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Notices of the Royal Aëronautical Society.

Patron.

Wing Commander His Royal Highness the Duke of York, R.A.F., has graciously consented to become a Patron of the Society.

Honorary Fellows.

The Council have elected Air Marshal Sir Hugh Trenchard, Bart., K.C.B., D.S.O., and Commander J. C. Hunsaker, U.S.N. (C.C.), Assistant for Aeronautics to the Chief of the Bureau of Construction and Repair of the U.S. Navy Department, Honorary Fellows of the Society. The list of those upon whom this distinction has been previously conferred is as follows:—Mr. P. Y. Alexander, Major B. F. S. Baden-Powell, Professor W. H. Dines, Lieutenant-General Sir David Henderson, Major-General Sir Frederick Sykes.

Chairman.

Air Commodore H. R. M. Brooke-Popham was, as a result of the Council Ballot, declared duly elected Chairman of the Society for the year 1920-1921, at a Council Meeting held on June 15th. He will assume office in October next.

Wilbur Wright Lecture.

Prior to the Wilbur Wright Lecture which was delivered by Commander J. C. Hunsaker at the Central Hall, Westminster, on June 22, a Council dinner was held at the Carlton Restaurant, which was honoured by the presence of H.R.H. the Duke of York. The other guests were:—Sir E. H. Tennyson d'Eyncourt, Air Vice-Marshal Sir E. L. Ellington, Wing Commander Louis Greig, Major Melvin Hall, U.S.A., Commander J. C. Hunsaker, U.S.N., Commander E. S. Land, U.S.N., the Marquess of Londonderry, Major-General E. D. Swinton, Major-General Sir F. H. Sykes, Mr. Griffith Brewer, and Mr. H. White Smith (Chairman of the S.B.A.C.). The following members of Council were present:—Major F. H. Bramwell, Air Commodore H. R. M. Brooke-Popham, Brigadier-General R. K. Bagnall Wild, Major-General Sir R. M. Ruck, Lieutenant-Colonel A. H. Burgoyne, M.P., Wing Commander T. R. Cave-Browne-Cave, Sir Robert Hadfield, Lieutenant-Colonel M. O'Gorman, Mr. A. Ogilvie, Mr. F. Handley Page, Mr. A. V. Roe, Mr. Holt Thomas, Major H. E. Wimperis, Major A. R. Low, and Lieutenant-Colonel W. Leckwood Marsh (Secretary).

Publications.

In the advertisement columns of the present issue will be found a statement of the aims and objects of the Society and details as to terms of membership, etc. These pages are being printed as a leaflet for distribution. The Secretary will be glad to forward a copy to persons whom members think are likely to be interested, on receipt of the necessary information as to names and addresses.

Election of Members.

The following members were elected in the various grades as shown at a Council Meeting held on June 15th :—

Fellow.—H. P. Folland.

Associate Fellows.—H. B. T. Childs, A.M.Inst.E.E., F. A. Foord, Capt. G. T. R. Hill, B.Sc., A. V. Jacques, B.Sc., A.M.Inst.Aut.E., Capt. V. A. H. Robeson, M.C., B. Thomson, B.Sc.

Members.—A. C. Clinton, E. A. Dobbs, L. Dove, H. A. S. Gothard, Major A. Innes, Capt. T. J. Gray, Major J. J. Meekin, H. Rogerson.

Student.—W. L. Le Page.

Foreign Members.—Lieutenant-Commander De W. C. Ramsey, U.S.N., R. H. Upson.

Aero Show.

Arrangements have been made for a room to be available (Stand Nos. 94 and 95) immediately on the left of the Hammersmith Road entrance, for the use of members during the International Aero Show to be held at Olympia from July 9th to July 20th. The room will be fitted up as a sitting room, and copies of the current aeronautical periodicals will be provided. A telephone will be installed for the convenience of members (the number will be Hammersmith 2130).

At the request of the Air Ministry the Society is also arranging a series of popular lectures to be given in the concert room opening out of the Hall during the afternoons of the show.

Empire Timber Exhibition.

A number of admission tickets for the exhibition at the Holland Park Skating Rink, from July 6th to July 17th, have been received and may be obtained on application to the Secretary.

Air Ministry Library.

Permission has been obtained from the Air Council for technical members of the Society to use the Air Ministry library for reference purposes on production of letters of introduction signed by the Secretary of the Society. Any members desiring to avail themselves of this privilege should therefore apply to the Secretary for a formal letter of introduction.

W. LOCKWOOD MARSH,
Secretary.

7, Albemarle Street, W.1.

PROCEEDINGS.

FIFTEENTH MEETING, 55th SESSION.

The Fifteenth Meeting of the Fifty-Fifth Session took place at the Central Hall, Westminster, on Tuesday, June 22nd, the Duke of York occupying the chair.

Before the Duke of York took the chair, General Bagnall Wild, Chairman of the Society, announced that the Duke of York had become a patron of the Society. He also announced that Air Marshal Sir Hugh Trenchard and Commander Jerome C. Hunsaker had been elected Honorary Fellows of the Society. Air Commodore Brooke Popham was announced as next year's Chairman of the Society.

The DUKE OF YORK said it was a great pleasure to him to preside at a lecture in memory of Wilbur Wright, the great American pioneer of aviation, and to have the privilege of introducing Commander Hunsaker, to whose lecture he was looking forward with great interest. He (the Duke of York) was going to make as few remarks as possible before calling on Commander Hunsaker, but some of those present might not realise his attainments so he (the Duke of York) would mention some of his many claims as an expert. Commencing the study of the theory of flight as far back as 1908 he had risen to be one of the greatest authorities on aircraft design. Among other notable things he designed the first airship built in America, designed the installation of the first Liberty engine to take the air, and was responsible for the general design of the N.C. trans-Atlantic flying boats, one of which, as they all knew, had succeeded in the trans-Atlantic flight. Finally, he now held the position of being responsible to the American Government for the design and construction of, not only all airships and all aeroplanes, but seaplanes as well. With these few remarks he had great pleasure in calling on Commander Hunsaker to proceed.

Commander JEROME C. HUNSAKER, Eng.D. (Construction Corps, U.S. Navy), then delivered the following "Wilbur Wright" lecture:—

NAVAL ARCHITECTURE IN AERONAUTICS.

Introductory.

As an American, I am very pleased to have been asked to read the Wilbur Wright Lecture for this year, and for a moment to stand in the reflected glory of my eminent countryman. Wilbur and Orville Wright were the pioneers who blazed the trail, and made the first clearing in the wilderness. We engineers who follow later are only applying modern machinery and methods of intensive cultivation in their original field. We should, therefore, keep in mind the fact that this field is given to us in trust to keep fertile, that its yield of benefit to mankind shall not diminish.

I have chosen to discuss the use of the tools of the Naval Architect in aeronautics as I consider that the time has now come to use them. The Naval Architect is a craftsman with both artistic and scientific traditions, and the art he practises has a technique perfected by the experience of generations.

It is only a few years since the Wrights gave the aeroplane to the world, but four of those years were years of astonishing activity, and the experience of those years is worth more than that of forty ordinary years. There is already a vast store of experience available which the Naval Architect's methods can analyse, classify and reduce to useful engineering terms.

While aeronautics as a useful art and a science is new, Naval Architecture is hoary with age. Noah probably considered and evidently reached a successful solution of the very problem of animal transport by sea that confronted our Naval Architects in the Great War. King Hiram of Tyre must have had a very fair Naval Architect who could fashion ships from cedar of Lebanon with a factor of safety and a range of stability adequate to cope with Atlantic storm waves. Archimedes, however, is generally recognised as the father of Naval Architecture. He first developed the laws of displacement and buoyancy, and is credited with the construction in 264 B.C. of the Syracusia of 6,000 tons—a veritable Dreadnought of antiquity.

The Naval Architect practises an art with scientific methods. He applies mathematics, especially geometry, in establishing lines, displacement and stability. He applies the methods of the Civil Engineer in matters of structural design. In matters of resistance and propulsion he is guided by the theory of hydrodynamics. But in all of these applications, the sure and true guide has been experience. From that remote age when the hollowed-out log canoe replaced the solid tree trunk down to the days of sail and steam, the Naval Architect has based his new design upon his last. Factors of safety and coefficients of all kinds used in apparently theoretical or frankly empirical formulæ have been really factors of experience.

The Naval Architect's problem deals with the sea, and we cannot pretend to know much more of its mysteries than that Syrian landsman who marvelled at the way of a ship in the midst of the sea. The forces of nature are still incalculable, but the design of a vessel to be staunch and safe is not such a dark and dreadful adventure. Confidence comes from experience and the Naval Architect's most powerful assistance comes from the scientific analysis of that experience to reduce its lessons to engineering terms.

The Naval Architect has available a priceless store of learning accumulated by generations of shipbuilders which, with skill and judgment, he can make serve him. He cannot afford to lean too heavily on the past, however, and where a new type of vessel must be produced, imagination and judgment of a high order are necessary. There is an artistic side to Naval Architecture, and for many craft the artistic feeling or " flair " of the designer distinguishes an advance in the art from a routine product.

In aeronautics I have yet to see a design representing a marked advance in the art made either without this artistic feeling for form and proportion or made wholly without reference to the lessons of the past.

General comparisons are impossible, but it seems to me that in England aircraft designers have followed the Naval Architect's methods more than in other countries. This is, perhaps, natural in the first maritime power of the world. In England, also, I find a very extensive application of the results of experimental research, both model and full scale, which really is experience interpreted and analysed by scientific methods.

In France I see less influence of experience and perhaps more originality of invention as shown by occasional radical departures, omitting intermediate steps of development.

In Germany there was once a tendency to " professorial designs " based too strictly on theory, resulting in strange and awkward structures like the Taube types. During the war something happened to reverse this policy, and we saw a series of machines developed step by step, obviously from experience.

In America we have suffered from the designs of the inventor without experience and from the practical rule-of-thumb man without theoretical landmarks to guide him. On the whole, the successful designs have been produced by men of imagination and judgment applying analysed experience with the best theoretical and engineering information available.

For very small machines the inventor type of designer has been very successful at odd times. He hits on a good solution, and by a process of cut and try eventually works out the faults before his patience or purse is exhausted. For large machines and airships the time and expense required are too great for cut and try methods. A large flying boat or an airship is a success or failure on her first flight. If badly overweight, unstable or out of balance there is no chance to rebuild.

In our Navy we look with suspicion on the man who is more concerned with the method of doing things than in the actual doing of them, and to avoid any misunderstanding, I must say here that I wish to make my point as to the utility of the Naval Architect's methods in aeronautical engineering by attempting actually to do a few of the things which appear to be needed at this time. This work I have thrown into appendices attached to this Paper.

I will not take time to read each complete appendix but will discuss them briefly. I trust that if my technical friends will find time to look into them, they will find them useful.

ABSTRACT OF APPENDIX I.

Weight Estimation.

Both the aeronautical engineer and the Naval Architect risk their reputations with weight estimates. A ship must float on her designed water line and an aeroplane must fly with the wing surface provided. Serious overweight in either case marks a failure. It is only rarely that vessels are discovered to be much overweight, but, unfortunately, overweight has been all too common with aircraft. Naval Architects are able to estimate weight with fair precision from unit weights gleaned from past experience and to check this estimate by calculation from the drawings. During construction, weights are controlled by weighing everything that goes aboard the ship. For aircraft, the practice of rigid weight control has not been well established either in the shop or in the drawing office. Very often construction is commenced before the drawings are completed, and during construction changes and alterations are incorporated without reference to their cumulative effect on the weight. A proposed change may be approved on its merit and not with reference to a definite weight allowance.

It is essential that before construction, or even detail design is commenced, a weight estimate should be made in the nature of a weight allowance which shall be treated like a bank balance and on no account to be overdrawn.

Such a weight allowance must be made from the general design drawings before the details are developed and necessarily is based on past experience with a similar type of construction. This is the Naval Architect's method, and to avoid guess-work requires extensive records and weight returns from actual work.

The matter of weight estimation for various types of aeroplanes is not really such an inaccurate procedure even in the case of an apparently radical departure from previous types of construction. I have assembled published weight data for several hundred different aeroplanes and seaplanes—British, French, Italian, German and American—from the smallest to the largest, and while the returns in any individual case may be unreliable, the general trend is usually quite definite. It appears that no designer, whether using solid wood, hollow wood or metal, is getting something for nothing, and, in general, the percentage weights for machines of similar type are remarkably alike.

If this conclusion be established, a designer may estimate the weights of a new design with some degree of confidence provided he has data for a somewhat similar type to work from. In the tables of Appendix I., I have given weight data for machines which are supposed to represent successful designs of adequate strength and power, eliminating all that I know to be weak structurally or grossly underpowered, or otherwise classed as failures. There may, however, remain

some types which ought to be eliminated or for which the data is in error. However, the plots give little weight to an individual case and are used to establish the general trend of the averages.

I have burdened the Paper with the entire mass of data as designers may have use for it in some other form, or may wish to examine more closely the credibility of the evidence. Also, this collection of the weights of present-day machines, in a way, marks the state of the art.

The data is summarised on charts to furnish a guide for use in preliminary design. The following general conclusions appear to be established :—

(1) The weight of wings, struts, wires and tail surfaces amounts to about 20 per cent. of the gross weight for all types.

(2) The weight of body, fuselage, landing gear, boat hull, etc., trends downward from 22 per cent. of gross for one-ton machines to 15 per cent. of gross for 20-ton machines.

(3) The weight of power plant also trends downward from 30 per cent. for small to 20 per cent. for large machines.

(4) The weight light for machines from the smallest to the very maximum sizes has to-day a lower limit at about 53 per cent.

(5) For large flying boats and large aeroplanes the weight light is about the same.

(6) The structural weight is high for low-powered machines and low for high-powered machines, and in general the best weight carriers show about 18lbs. per horse power.

(7) Similarly, the structural weight is high for low wing loading and vice versa.

(8) The wing loading is found to be greater for the larger machines, reaching a maximum of nearly 12lbs. per sq. ft. for the large flying boats.

(9) It appears that all the evidence from past practice indicates that large flying boats can safely be given a higher wing loading and a higher landing speed than land aeroplanes, and, hence, have a distinct advantage as weight carriers for commercial purposes.

ABSTRACT OF APPENDIX II.

Metacentric Height.

They that go down to the sea in ships are wont to criticise a ship in an offhand manner, her wetness or dryness, her period of roll, whether she will sail sweetly or prove crank, and other mysterious details of her intimate behaviour among waves. And all this with an apparent confidence which to a layman must betoken a wisdom such as Solomon's. But there really is little mystery about it, for nearly 175 years ago, Bouguer,[1] the father of theoretical naval architecture, hit upon the brilliant conception of a metacentric height to serve as a measure of stability. Since that time thousands of ships have gone to sea

(1) Bouguer, "Traité du navire," Paris, 1746.
L. Euler, "Scientia Navalis," St. Petersburg, 1749.
Atwood, "Stability of Ships," London, 1796.
Chas. Dupin, "Applications de Géometrie et de mecanique à la Marine," Paris, 1822.
P. J. Moreau, "Principes fondamentaux de l'equilibre," etc., Lorient, 1830.
J. M. C. Duhamel, "La stabilité des corps flottants," Paris, 1832.
H. Moseley, "On the Dynamical Stability and on the Oscillations of Floating Bodies," London, 1874.
F. K. Barnes, "On the Metacentre and Metacentric Curves," "Naval Science," Vol. III., London, 1850.
E. J. Reed, "A Treatise on the Stability of Ships," London, 1885.

with cargoes stowed in an indefinite number of arrangements, and millions of passengers, as well as animals, have been made violently or only mildly ill. Some ships carried sail well, others were crank; some ships proved stiff but violent in motion, others capsized. Every sort of marine disaster has occurred and as a result an enormous store of experience has been accumulated. In nearly all such cases a knowledge of the metacentric height of the vessel has proved to be a valuable index to her behaviour.

The metacentric height or distance from the centre of gravity to the metacentre is the limit of the distance Gm on Fig. 1 as the angle of roll $\Delta\theta$ from the normal or upright position becomes small.

A ship is stable if there is a righting moment for any angle of heel. The initial stability is measured by the metacentric height in the upright position. If the ship be already heeled through a large angle, she is still stable if she still has a positive metacentric height. There is thus to be considered the problem of range of stability or the angle of heel permissible before the metacentric height vanishes.

The period of a roll, neglecting damping, is given by the expression:—

$$t = \pi k / \sqrt{(g.Gm)}, \text{ where } k \text{ is radius of gyration.}$$

It appears that the rolling will be quick and hence uncomfortable when Gm is large. For an easy ship Gm should be small, but not so small as to impair the range of stability. For passenger steamers Gm may be made small with safety, but for warships it is necessary to provide a larger Gm than the gunnery officers would desire, to provide for stability in a damaged condition. Battleships sunk in action usually capsize before going under.

I have spoken so far of the "lateral" metacentre which controls the rolling of vessels. There is, of course, a strictly analogous "longitudinal" metacentre which controls the pitching.

The metacentric height is, of course, an index to the statical condition only, but for all practical purposes has served the naval architect very well. The dynamics of rolling among waves[1] are even more elusive than the theory of aeroplane stability so beautifully developed by Bryan[2] and Bairstow.[3] And just as the naval architect proceeds to design good vessels by using his practical judgment based on experience and a knowledge of the metacentric height regardless of the mathematics of resisted and synchronous rolling, so do we find aeroplane designers producing good aeroplanes, using practical judgment and very little mathematics. I have yet to find anyone in a successful aeroplane design office solving simultaneous differential equations of motion.

Unfortunately, the aeroplane designer has not 100 years of experience to draw on and there has been no ready handle on an aeroplane to seize upon like a metacentric height. Consequently, a great deal must be left to judgment, artistic feeling, comparison with other aeroplanes, and eventually to the opinion or prejudice of the test pilot.

The need for some ready means for off-hand judgment of aeroplane stability and manœuvrability has been felt for a long time. The mathematics of stability are too cumbersome for practical use, and require extensive wind tunnel research

(1) D. Bernoulli (Prix de l'Academie des sciences), Paris, 1757.
Dupuy de Lôme, "Mem. G.M.," Vol. IV., Paris, 1859.
Wm. Froude, "Proc. Inst. Nav. Arch.," Vols. II., III., IV., XIV., XVI., London.
Rankine, "Proc. Inst. Nav. Arch.," Vols. V., XII., London.
Scott Russel, "Proc. Inst. Nav. Arch.," Vol. IV., London.
Bertin, "Les vagues et le roulis," Berger-Levraut, Paris, 1877.
Reech, "Théorie du roulis, etc.," Paris, 1870.

(2) G. H. Bryan, "Stability in Aviation," Macmillan, London, 1911.

(3) L. Bairstow, Advisory Committee for Aeronautics, R. & M., 116—122, London, 1914.

to establish the necessary constants. It is my experience that we can build and fly a small aeroplane in less time than it takes to perform the stability calculations.

The general case of the disturbed motion of an aeroplane is not simple, but the longitudinal or symmetrical motion is two-dimensional and can be considered apart from the lateral or asymetric motion. For the longitudinal motion, we are interested in the pitching oscillations and the criterion that such oscillations be stable. For aeroplanes of normal design, if there be a righting moment called into play by any angular deviation from the normal attitude,[1] the pitching oscillations so produced are strongly damped. In other words, if an aeroplane be statically stable it is also dynamically stable, so far as pitching is concerned.[2]

My colleague, Commander Wm. McEntee (C.C.), U.S. Navy, suggested the application of the naval architect's metacentre to measure the statical stiffness of an aeroplane's longitudinal stability. I have assembled the data from all of the wind tunnel tests on complete model aeroplanes that I had available, and have computed the metacentric height from the observed slope of the curve of pitching moments in the following manner:—

$\Delta M/\Delta\theta$ = slope of curve of pitching moment.

But $M = (\Delta M/\Delta\theta)\,\theta$.

And $M = WGm \sin\theta = WGm\theta$, for small angles,

Then $Gm = (1/W)\,(\Delta M/\Delta\theta)$.

This algebraic definition of Gm has the dimensions of a length and amounts to from 2 to 12 feet for modern aeroplanes and flying boats. It is directly proportional to the coefficient M_w of Bairstow's notation, but immensely more easy to remember for use for purposes of comparison. It is also proportional to the centre of pressure motion. To give the length Gm a physical meaning, Fig. 2 has been drawn to an exaggerated scale. It will be noted that m is the intersection of resultant lift vectors for successive angles of incidence, resolving the lift component at a line of reference through the centre of gravity in the direction of motion. As an intersection, m is, therefore, dependent on the angle of incidence, and it can be shown that for large angles of incidence m approaches G. The metacentric height grows less and tends to vanish when the aeroplane stalls. This is, of course, entirely consistent with the unfortunate natural phenomenon which makes a stalled aeroplane notoriously unstable.

Fig. 3 is a graphical representation of a wind tunnel test of a model of a flying boat. It shows how Gm diminishes for larger angles of incidence until it vanishes at about 12°.

Table I., of Appendix II., gives the metacentric heights calculated from wind tunnel tests on complete models (ex propellers) of 27 types. Aeroplanes both small and large are included, as well as float seaplanes and flying boats. We have a truly miscellaneous collection, with British, French, German and American examples, which should give a good test of the naval architect's method of classification by means of metacentric height.

Designers have, in general, been giving a greater metacentric height for great chord length, which appears reasonable. Plotting the metacentric height against chord length on Fig. 4 brings this out clearly. The points group themselves about a straight line.

It therefore seems possible from a knowledge of the relation of chord to metacentric height for any design to say with some confidence whether the machine will be more or less stable (stiff) longitudinally than the average, and whether such stability will be reasonable or abnormal.

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(1) A positive value of M_w in Bairstow's notation.

(2) Hunsaker, "Dynamical Stability of Aeroplanes," Smithsonian Misc. Coll., Vol. LXII, No. 5.

Effect of Change in Angle of Stabiliser Setting.

In Table II. of Appendix II. are assembled calculations of Gm from wind tunnel tests in which the setting of the stabiliser has been altered. To bring out the effect of such changes, Fig. 5 has been made where Gm is plotted against the angle of stabiliser setting, *i.e.*, the angle between the stabiliser and the wing chord. It will be noted that the points fall near straight lines whose slopes are the change in Gm per degree change in angle of stabiliser setting. This slope is denoted by $\Delta Gm/\Delta\beta$ and is plotted against the ratio of horizontal tail area/ to wing area in Fig. 6.

It is found that $\Delta Gm/\Delta\beta$ depends on the area of the horizontal tail surfaces in a straight line function. The slope of each line of Fig. 5 when plotted on Fig. 6 falls near either one or the other of two straight lines which have substantially the same slope.

It is to be noted from these lines that the tractor type tail surface is less efficient than the N.C., a pusher type tail surface, a conclusion consistent with previous experimental work. (A. C. A. R. and M. 438 and 505.)

Effect of Change in Stabiliser Area.

The values of Gm for changes in stabiliser area are given for various machines in Table III. of Appendix II. These values when plotted against percentage of the original area (see Fig. 7) lie near straight lines. The variation in the slopes of these lines is small and seems to be independent of the original size of the stabiliser.

Fore and Aft Movement of Centre of Pressure.

In order to study the movement of the centre of pressure, the 4° vector location, or line of action of total air force for an angle of incidence of 4°, has been determined for a number of machines and for various stabiliser settings. These locations, which may be found in Table IV. of Appendix II., are plotted on Fig. 8. For each machine the points are found to lie near a straight line, the line for the larger machines having, however, a greater slope than those for the smaller machines.

In Fig. 9 the slopes from the lines of Fig. 8 are plotted against the wing chord of the machines which they represent. The fact that all of the points so plotted lie very nearly on a straight line indicates that the movement of the 4° vector with change in angle of stabiliser setting is almost entirely dependent upon the wing chord. The average value of the movement of the 4° vector per degree change in stabiliser setting is found to be 0.033 × chord.

This movement is forward if the normally negative angle between stabiliser and wing chord is increased, and vice-versa.

In the foregoing discussion I have tried to bring out the fact that an aeroplane actually has a metacentric height which is entirely under the control of the designer. It would very much clarify our knowledge of aeroplanes if we knew the initial metacentric height the designer gave it. Knowing this, we could judge with some degree of confidence whether the machine is reasonably stable for its type. Further, if we knew the metacentric height as designed, the effect of stabiliser adjustment could be considered more intelligently than it is at present.

The adjustable stabiliser is a very useful and convenient device for altering the balance of a machine, but it also alters the metacentric height. It is quite possible, by excessive use of this means to balance up an otherwise tail heavy machine, entirely to destroy the metacentric height and hence the stability. The tables and charts I have given here may prove useful, I trust, in the consideration of such a possibility for a particular design.

ABSTRACT OF APPENDIX III.

Control Surfaces.

I doubt if there is any one part of an aeroplane which has caused more trouble than the control surfaces: rudders, elevators, ailerons. The three rudder system of control invented and developed by the Wrights made flight possible. It is fundamental for three dimensional space. All of the experimenters before the Wrights failed for lack of proper control. Consider the machines which did not really fly of Lilienthal, Montgomery, Langley and the other pioneers. As soon as the Wrights showed how to control an aeroplane, any boy could make his own glider. Yet, although the fundamental nature of this discovery is universally recognised, we know little more about the design of such control surfaces than the Wrights taught. Control surfaces are proportioned for aeroplanes and airships largely by judgment and experience. There is no sure calculation in our handbooks, and the designer risks his reputation and the test pilot risks his life on many new machines. For civil aviation it is especially important that machines sold to the general public have adequate control surfaces. This is quite as important as to require adequate factors of safety and apparently not one-tenth so difficult. However, the areas and proportions of control surfaces are the only things not covered by specifications. We depend on the test pilot to state whether he finds the control certain and easy.

When an important feature of design is so largely a matter of judgment and feeling we look to naval architecture for an analogous problem. The rudders of vessels are made large or small, depending on the manœuvrability desired. The actual design of such rudders is a matter of judgment and experience. For a merchant ship a rudder area from 1/75th to 1/100th the area of the longitudinal section of the ship is found to be quite satisfactory for ordinary steering. For warships the turning circle is a military feature, and to give quick manœuvring a rudder relatively twice as large is used. The exact size and shape of rudder to use for any design are determined from an analysis of the rudder proportions of ships of similar type whose turning circles and general behaviour are known.

Such mathematical theory of the turning of ships as exists is used in selecting the important variables in the problem, but the analysis results in empirical coefficients.

The naval architect's method is applied to obtain empirical coefficients for the control surfaces of aircraft of the various types in the third appendix to this paper. I have there assembled data for a large number of aeroplanes and airships which are generally supposed to be successful. The various machines are classified by type, and the coefficients for each type are averaged in Table I. of Appendix III. It is interesting to note that the average coefficients for very different types are practically the same. The coefficients for the individual machines vary more widely and reflect the individuality of the designers. In particular, the average for 15 German aeroplanes shows an aileron area only eight per cent. of the wing area, while the averages for Table I. lie between 11 and 13 per cent. It must be that the Germans did not desire a powerful lateral control.

Table X. of Appendix III. shows similar coefficients for the control surfaces of airships. Here we have less uniformity and it would appear that airship designers had not yet settled upon simple rules. However, experience with airships is still relatively limited when we consider the immense numbers of aeroplanes that have been built.

Turning now to the proportioning of the control surfaces; both experience and wind tunnel experiment teach that the best control surfaces are narrow trailing portions of fixed surfaces. This makes for simplicity both structurally and aerodynamically. But a difficulty arises in large machines where it is necessary to balance the surfaces to relieve the load on the pilot. I know of nothing more

embarrassing than to have a balanced aileron or elevator flutter violently in flight, unless it be to have the balancing portion twist off entirely.

The aeronautical engineer needs some simple rule for the design of balanced control surfaces. It is not practicable to make elaborate wind tunnel experiments for every design and it is not safe to depend too much on judgment. In order to use simple rules, aeroplane designers must adopt forms which lend themselves to simple computations. Many of the forms of balancing in common use are aerodynamically entirely indeterminate. For example; consider the types of balancing shown on figure 2 of Appendix III. No man can calculate with confidence the force of the air spilling off a wing tip and striking an overhanging portion of aileron. There is certainly a vortex there of a most uncertain nature. Similarly, in the so-called "dove-tail" method of balancing where the balancing portion of the control surface works in a recess in the fixed fin, there is a mutual reaction between the two surfaces which is highly indeterminate. The Zeppelin rudders have until recently had this form of balance, but I have noted with satisfaction that the "Bodensee" has changed to a partially overhung type of rudder.

The naval architect has long ago been through similar troubles with ships' rudders in rear of the dead wood aft, and concluded that he would use a plain trailing rudder hinged to the stern post with an underhung balancing portion projecting into clean water. The dead wood is cut away forward of this balancing portion. Spade rudders are used where they cannot influence the dead wood or be blanketed by it.

If aeronautical engineers would agree to use simple overhung balanced control surfaces, a simple calculation will serve for their design. Table XI. of Appendix III. summarises a calculation for such control surfaces on a number of machines where the centre of pressure of the trailing portion is taken at 0.3 chord length and for overhung portion at 0.2 chord length. The ratio of balancing to righting moments gives a coefficient which for the normal case free from blanketing or slip stream effects should not exceed .65.

To sum up, control surfaces of the usual type can be designed by use of coefficients taken from similar type machines of normal behaviour with every assurance that the manœuvrability of the new design will prove normal.

ABSTRACT OF APPENDIX IV.

Normand's Weight Equation (Rigid Airships).

There is nothing more profitless than an argument over a proposed design between the operating personnel, who are always demanding enhanced military characteristics, and the constructors, who are prone to object to change on the grounds that their pet design will be spoiled. Most likely both sides advance very strong arguments to support a particular view of the matter. But such a discussion should not rest on a basis of argument alone, else it degenerates into something resembling that ancient impasse: "Are the mountains better than the seashore?"

As a matter of fact, the effect of any proposed change in military characteristics can be calculated in a sufficiently approximate manner to make possible a decision based upon evidence.

For rigid airships which closely resemble vessels, I propose the use of a naval architect's method for analysing such problems due originally to that eminent French designer of torpedo craft, M. Normand, and subsequently extended and perfected by Prof. Hovgaard. By Normand's method, a rapid estimate can be made of the cost in displacement involved by almost any proposed change in the ship.

In the fourth appendix to this paper, I have developed Normand's method

to apply to airships by forming the so-called weight equation as the sum of the principal weight groups each expressed in terms of the independent and dependent variables of the design. This weight equation is then differentiated to exhibit the effect of a change in any of these variables and formulæ deduced, analogous to those which apply to vessels, by which a quantitative estimate can be made for the effect of such change.

An airship can be changed in two ways, by preserving similitude of form and permitting the volume to vary or by holding constant volume and changing the ratio of length to diameter. Considering the first case, the factor of proportionality N computed in the fourth appendix is about 4.5 for a ship of L.49 type. This means that an addition of 1,000lbs. to the weight of any item in the ship calls for such increase in other items, to keep the performance the same that the total lift must be increased 4,500lbs. For battleships N is of the order of only 2.5, indicating a much more favourable situation. The principal reason airships appear to be at a disadvantage comes from the longitudinal members of the hull structure whose weight increases as the fourth power of the length of the ship.

Consider, now, the effect of holding volume constant and changing the fineness of the ship. The longitudinal members of the hull vary in weight as the third power of the length and the first power of the diameter, while the weight of the transverse frames varies as the fourth power of the diameter. If the ship be fattened up, weight is saved on the longitudinals and lost on the transverses. But if the ship be too long originally there will result an important net saving in weight.

Finally, I have applied the method to a rigid airship of the Zeppelin type (L.49) in an example to show how practical answers may be obtained. The displacement of L.49 is assumed to be 1,940,000 cu. ft., or 129,800 lbs. If it be proposed to make a new design which shall be similar to L.49, except to have 2,000lbs. more bombs, a 25 per cent. heavier outer cover, a 15 per cent. lighter system of longitudinals and transverses and 5 per cent more speed, the new ship must be given 13,890lbs. more displacement, or a total volume of 2,145,000 cub. ft. The net price paid in displacement is, therefore, about six tons.

On the other hand, if the ratio of length to diameter be reduced from 8 to 7, the ship can be built lighter, and the calculations show that a saving in the new design of nearly five tons is due to this change of form alone. As a final result, a new ship resembling L.49 might be built having the proposed changes incorporated, and only be slightly larger than L.49; *i.e.*, 1,990,000 cu. ft. The principal dimensions compare as follows:—

Length L.49, 643ft., new ship 584ft.
Diameter L.49, 78.7ft., new ship 83.5ft.

It would appear that a decrease in the length-diameter ratio is of great advantage, and were it not for the necessity to consider the height of existing hangar doors, airships might well be made fatter than the German models.

ABSTRACT OF APPENDIX V.

The Model Basin.

Naval architects first came into aeronautics in connection with seaplanes. The aeroplane was developed before the seaplane and at first the great problem was to design the boat or float so that the seaplane could actually leave the water. The early attempts were rarely successful, and it was not until a satisfactory form of planing bottom had been developed by model experiments in the towing basin that any consistent success was had. The contribution of the model basin to aeronautics is too well known to be gone into here. Existing methods and apparatus which had been developed for the study of the resistance of ships were immediately available so soon as it could be demonstrated that Froude's law of

corresponding speeds applied to the planing action of flying boats. Such a verification was soon demonstrated by the successful performance of seaplanes designed from the results of model tank experiments.

It is now possible to test in the tank, at small expense and no risk, any proposed form of planing hull and to determine whether or not such a hull is worth constructing full scale. It is, therefore, possible to eliminate a great many types which would prove to be disappointments, and it is also possible to experiment with a great variety of minor modifications in form to determine the effect upon general behaviour of these modifications. As a result of the last four years' work at the experimental model basin at the Washington Navy Yard by my colleagues, Commander Richardson and Commander McEntee, two forms have been developed which for general purposes we have found superior to the others. One is a pontoon which has been used on single and twin float seaplanes, and the other is a form of hull which was used for the N.C. flying boats. These forms may not be the best known, as regards resistance or any other single feature, but have proved of all-round utility. With the permission of the Chief Constructor, I am giving the lines and resistance curves for these models in the fifth appendix as they are a very fair representation of the present state of the art.

It will be noted that these forms are both what is called "vee bottom," and although this form of bottom behaves well in rough water and reduces the shock of landing, it is objectionable on account of the spray thrown out from the chine. For a twin float installation, this is often a serious matter as the spray gets in the propeller and causes trouble. A recent scheme to protect the propeller from spray has been suggested by Mr. Grover C. Loening. For twin float machines, he proposes floats with a bottom sloping outboard from the inner chine. This appears to eliminate all spray between the pontoons throwing it outboard.

The experiments in the towing tank record all those things which can be measured, but do not record the spray and wave formation. We have recently undertaken the study of the wave formation which accompanies a planing boat by the use of an ultra-rapid motion picture camera, which takes pictures at eight times the rate of the commercial machine. When projected on a screen at ordinary speed (16 per second), this gives a view of the whole wave system to a microscopic time scale. This work is too new to warrant any conclusions from it, but I mention it as being a suggestive means of studying a very complex state of affairs.

An extension of the usual work of the model basin has led to the investigation of the strength of flying boat hulls to resist the shock of landing. For this purpose, accelerometers are mounted in the hull. Attempts to use the R.A.F. accelerometer were disappointing. This instrument had been used in the air for acrobatic flying with very satisfactory results, but it appears that the force at landing is too suddenly applied to be easily measured by this type of apparatus. Another type of accelerometer, developed by Dr. A. F. Zahm, has been used with very consistent results. This instrument depends only on the deflection of a series of light vertical springs by a series of masses and gives a definite maximum.

With this instrument landings have been made in smooth water and it appears that the vertical component is seven times gravity and the horizontal component 2.5 times gravity. An R.A.F. instrument mounted alongside the Zahm instrument gave at the same time three times gravity and 1.7 times gravity, respectively. The large vertical components are noteworthy and appear consistent with our experience where engine foundations on flying boats and pontoon struts have failed, although they were designed for a load factor of eight.

Conclusion.

In this paper I have discussed in rapid succession five applications of naval architecture which could only be developed in detail in the appendices. Conse-

quently, I cannot expect to have demonstrated more than the existence of these methods of attack and to have advertised their utility. It will be noted that two principal methods only have been used.

The first is the *analysis of experience* by means of a comparison of percentage weights, percentage control areas, etc., for a large number of successful aircraft. Similarly an *analysis of experience* is attempted in the comparison of metacentric heights. Normand's method of differentiating a weight equation is also based upon experience, and the method will not attain its maximum value until weight statements for a great many more airships are available.

I cannot urge too strongly the general advantage to the art which would result from the full and frank publication of technical information regarding not only successful designs but failures as well. The failures in particular are priceless, but perhaps it is too much to expect of human nature that a post-mortem on a bad design will see the light of day.

The second peculiarly naval architectural method used in aeronautics is *model experimentation*. A theory of similitude, geometrical, mechanical or dynamical, is used to apply model basin tests of boat hulls, wind tunnel experiments on aerofoils, and model propeller tests. Such a general use of similitude in design is unique in engineering practice and forms the closest bond between the naval architect and the aeronautical engineer.

The *analysis of experience* is really a statistical method for which trustworthy data in quantity are necessary. Given the necessary information, the naval architect's methods not only reveal the past and present state of the art as represented by engineering coefficients and averages, but also show the trend of the more successful designs. In that way, future development can be predicted and the most promising directions for improvement.

To avoid leaving the impression that the naval architect is looking backward exclusively, I should like to take the opportunity to recall the astonishing success of the little airship built by Dupuy de Lome in 1872. This eminent naval architect attained by his professional skill the maximum success which the state of the mechanical art at that time permitted.

His little hand-propelled " Aerial Ship " exhibited all of the principal features of our modern non-rigids in their fundamental forms. Control and stability were correctly understood and provided for. An air speed meter was also provided. The requirements of our modern theory of suspending a car below a non-rigid gas bag were met by his suspension system. A ballonet and blower were used in accordance with good practice. More remarkable still, Dupuy de Lome made the envelope of two-ply rubberised fabric and doped it with a very fair gelatine, glycerin, acetic acid varnish to make it tight.

I quote from a contemporary account :—(1)

> " The stability was something marvellous; several persons moving about in the car at the same time did not produce any oscillation. A descent was intentionally made from 1,020 metres to 600 metres without making use of the ballonet. The folds in the balloon then became very marked, and it was interesting to observe the tension of the various ropes as they maintained the major axis of the balloon in a horizontal position.
>
> " The complete agreement of the results of the trial with those foretold by the inventor will be obvious to everyone. Such an agreement, usually so rare, is the more extraordinary as in this case all the bases of calculation had to be discovered.
>
> " Henceforth aerial navigation may be said to possess a theory of stability and propulsion. The true history of ballooning will date from the

(1) Leclert, " Naval Science," April—October, 1872.

2nd February, 1872, a new era marked by the invention of the navigable balloon, and rendered illustrious by the name of M. Dupuy de Lome, so well known in connection with scientific progress and invention."

The name of Dupuy de Lome deserves to be remembered not only as the leading naval architect of his day, but also as the first naval architect to apply his art to aeronautics.

In closing, I should like to express my appreciation of this opportunity to present before this Society some of the later knowledge of the Navy Department in an effort to make at least a small return for the very valuable work which the Royal Aëronautical Society has done in publishing and distributing for the benefit of the art the best knowledge of British Aeronautical Engineers. My Chief, Admiral D. W. Taylor, Chief Constructor of the Navy, especially welcomed this continuation and extension of the cordial relations established during the war, and authorised me to disclose anything or everything of value in the possession of the Bureau of Construction and Repair.

The Secretary of the Navy is much pleased that an officer of the United States Navy has been invited this year to read the Wilbur Wright Lecture, and desires me to express his gratification. The foundation of the Wilbur Wright Lecture is an institution very much to the credit of the Royal Aëronautical Society, which is not only the oldest Aeronautic body in the world, but also the first to found a permanent memorial to my countryman. This early recognition of the Wrights by this Society has ample justification, for this very Hall might not still exist to-night had not Wilbur and Orville Wright's invention been overhead to protect it.

In honouring Wilbur Wright, we meet on a common ground. Friendly relations between our countries will be furthered by Trans-Atlantic flying, and it seems very appropriate that the most intimate contact should be maintained by those technical and scientific workers who are striving for the same end: the improvement and application of the gift of flight left us by Wilbur Wright.

The DUKE OF YORK said he knew he was speaking for all those present in heartily congratulating Commander Hunsaker on his most interesting lecture, which they had just heard. Unfortunately he (the Duke of York) was not a technical expert and he had to confess that he was lost in admiration at the capability of a mind which could deal with such a wealth of practical detail and he would have to leave it to others to descant on the salient points of technical interest. What had struck him most, as being possibly of a more general interest to all present, was that it was indeed a sign of the good feeling and co-operation between the United States and ourselves when an authorised body like that Society extended an invitation and imparted such information to them. But he was in a position to state that the American Government had gone still further and had authorised Commander Hunsaker to publish in the official organ of the Royal Aëronautical Society certain information (too technical to be dealt with in the lecture that night) as to the construction of the hulls of the N.C. flying boats—information of extreme importance to designers in other countries and which would be imparted for the first time in the official organ of a British society. On behalf of those present he would thank the American naval authorities for their extreme courtesy and acknowledge their great compliment. That co-operation and good feeling between our two nations—which developed during the war when, on a common ground and in a common cause we fought, with our Allies, against a common enemy—must never be lost. In spite of many signs to the contrary there was one fact which, to him, was fundamental—Britons and Americans could never be anything else but friends; and if proof were wanting they had only to look to events such as the lecture that night to realise what an understanding there was between the two nations. Once more he would congratulate Commander

Hunsaker and ask those present to join with him in cordially thanking the Lecturer.

General BAGNALL WILD then proposed a hearty vote of thanks to the Duke of York, and Commander LAND, U.S. Navy, who seconded, said that it was an honour for which he was deeply grateful to be present that evening to join hands with his cousins here as well as with his brothers from America.

He was also deeply grateful for the honour conferred upon one of his best friends and associates, Commander Hunsaker, in making him a Fellow of the Royal Aëronautical Society, and in asking him to deliver the Wilbur Wright Memorial Lecture. If he might be permitted, he should like to congratulate the Royal Aëronautical Society on its foresight, initiative and courtesy in honouring Wilbur Wright, a man who gave all of his life to the art and science of aeronautics.

He was not going to discuss Commander Hunsaker's excellent paper, but he was forced to make one criticism on the first part of the paper, where he referred to early naval architects. He thought the Lecturer had been careless in omitting one of the earliest and most important naval architects who ever lived. He referred to a name that, unfortunately, had been used by those prone to slang as a term of ill-omen or bad luck. That is a discredit to a famous naval architect whose practical demonstrations of naval architecture far outshine the works of many of the men referred to by Commander Hunsaker. He referred to *Jonah*! who lived for three days in the belly of a whale, thus establishing a world record never equalled and seldom approached.

Changing from the ridiculous to the sublime, he wished to invite attention to the co-operation between British technical societies and American technical societies. This co-operation is well known and thoroughly appreciated on both sides of the "Pond." This is particularly true of the work of the Royal Aëronautical Society and respective Advisory Committees for Aeronautics. He could think of no better practical example of this co-operation than that which exists between the Air Ministry and the United States Navy Department in connection with the purchase of the rigid airship R.38, now under construction at Bedford. This airship is due for completion some time during the present year, and it was hoped to sail her successfully to America next spring. The co-operation of Great Britain and America was clearly brought out in the discussion of Sir Richard Glazebrook's paper recently read before this Society. No man can accurately estimate the value in Anglo-American relations of this close co-operation between the two countries. That it is valuable goes without saying. First, it is technically valuable to the science of aeronautics. Second, it tends to cement friendship and good feeling between the two countries—a consummation devoutly to be wished—and third, it creates a healthy rivalry and develops a spirit of sportsmanship which is not only a credit to both nations but is also a credit to humanity.

He recently had the pleasure of hearing H.R.H. the Duke of York make an impromptu speech at Olympia during the Royal Boxing Tournament. His subject was "Sportsmanship," and excellently he handled it.

To the mind of the speaker, sportsmanship is a wonderful word, glowing with meaning and symbolising the real man. We have innumerable examples, at the present time, of the excellent co-operative spirit engendered by sports carried out in competition with one another on both sides of the Atlantic.

We have been told on innumerable occasions just what won the war—food—ships—munitions—fleets—armies—*ad infinitum*. Might he be so bold as to tell them what really won the war? Sportsmanship!

It is embodied in the make-up of English speaking peoples as in no other peoples in the world. The British are noted the world over for their sportsman-

ship, and it is embodied in the Royal Family to a remarkable degree, as was evidenced by the Royal Chairman that evening, and that Prince of Sportsmen, the Prince of Wales.

Some people considered it a doubtful practice to praise the British at the present time. The speaker did not belong to that class. He sometimes felt that the relations between the two countries resembled a form of marriage vow. Some people thought that the marriage contract should consist of three words—" Bear and forbear." We should apply that maxim regardless of all the yellow journalism that may exist on both sides of the Atlantic.

Wise counsels will always prevail and we need not worry about what kind of Divorce Laws Parliament makes!

He was for America first, but as the little boy said when he grabbed the prize apple, " After me you come first." If that does not go down, he would prove to them that Sir Isaac Newton's law of gravity is erroneous, and they all knew that gravity brings everything down except the high cost of living.

In conclusion, he took pleasure, heartfelt pleasure, in seconding the vote of thanks proposed by General Bagnall Wild—and whenever the time is opportune he would be glad to add " three rousing cheers and a tiger " for our Royal Chairman.

The DUKE OF YORK briefly thanked those present for the warm response they had given him.

APPENDIX I.*

An attempt is made in the accompanying charts to make a graphical analysis of the weights of heavier-than-air craft from a purely empirical standpoint and to establish the trend of design, if any definite trend does exist. Some of the charts give negative results but, in my opinion, are still useful to explode certain theories as to the effect of mere size on performance.

For the purpose of this study, the following classification is used :—

Class 1. Single-seater aeroplanes.
Class 2. Two-seater aeroplanes (1 to $3\frac{1}{2}$ tons gross).
Class 3. Multi-engined aeroplanes ($3\frac{1}{2}$ to 9 tons gross).
Class 4. Multi-engined aeroplanes (9 tons and over).

Within each class there are three subdivisions :—

(*a*) Land planes.
(*b*) Float seaplanes.
(*c*) Boat seaplanes.

Class 1 and 2 overlap to a certain extent between 1 ton and $1\frac{1}{3}$ tons, but it was found to be more convenient to allow Class 1 to comprise all single seaters than to limit the weight to one ton.

The other classes were more or less arbitrarily assumed, but not until after considerable time had been spent on other classifications which did not prove to be as workable.

The three principal variables affecting the performance of an aeroplane are gross weight, pounds per horse power, and pounds per square foot, and these items are, therefore, considered to be fundamental, and variation of other items considered with respect to them.

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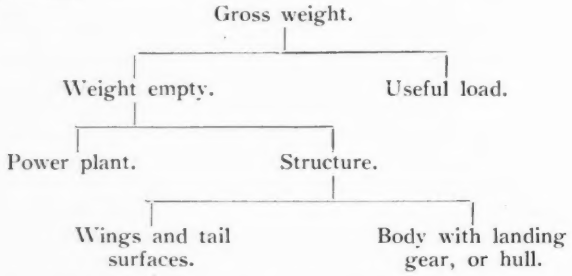
* I am indebted to my assistant, Lieut. R. D. MacCart, for help in the preparation of this Appendix.

The weight of an aeroplane is divided into its main groups in accordance with the following scheme :—



In order to make the body group comparable in all types of machines, there is included in it in the case of land aeroplanes, the fuselage and landing gear; in the case of float seaplanes, the fuselage, floats and struts; and in the case of boat seaplanes the hull and auxiliary floats. In order that the body weights of various types of boat seaplanes may be comparable, any outriggers which support the tail are included in the body group. The power plant group includes machinery with all accessories and tanks. The useful load includes fuel, crew and military load.

Fig. 1 of Chart I. shows the wing and tail weight expressed as a percentage of gross weight plotted against gross weight. A representative line drawn through the points indicates a uniform weight of 20 per cent. of gross. The points lie remarkably close to this line, and in general the points which lie above have a higher factor of safety or a lighter loading than the ones which lie below. The chief interest of this plot is the demonstration of constant percentage weight for the wing and tail group. The large machines, it should be remembered, have generally higher wing loadings and reduced factors of safety.

The U.S. Navy training seaplanes may be noted in a group above the line at 2,500lbs. These machines have a light wing loading and a high factor of safety.

At about 3,800lbs. and below the line is located the Curtiss HA float seaplane, which has a high wing loading and a moderate factor of safety.

The Curtiss H.S. boat seaplanes are in the vicinity of 6,000lbs. and very near the line.

The same may be said of the F.5 group at about 13,000lbs. and the N.C. group at about 25,000lbs.

Fig. 2 of Chart I. gives the body weight in percentage of the gross weight. A representative line drawn through this group of points appears to have a downward slope.

It will be noted that up to about 6,000lbs. the seaplanes lie considerably above the line, while above 6,000lbs. the seaplanes lie very near the line. Almost invariably the land planes lie below the line, indicating that the body weight of seaplanes is greater than that of corresponding land machines except in the very largest sizes. In large flying boats the hull, combining the functions of landing gear and fuselage, weighs about the same as the corresponding group of the aeroplane.

It is more difficult to find a representative line for Fig. 3, which is a plot of structural weight obtained by summation of the ordinates of Fig. 1 and Fig. 2. The different types are, however, segregated in a logical manner. The training machines (about 2,500lbs.) have a high percentage of structural weight as expected. The seaplanes and flying boats up to approximately 7,000lbs. have a noticeably higher structural weight than the corresponding land machines.

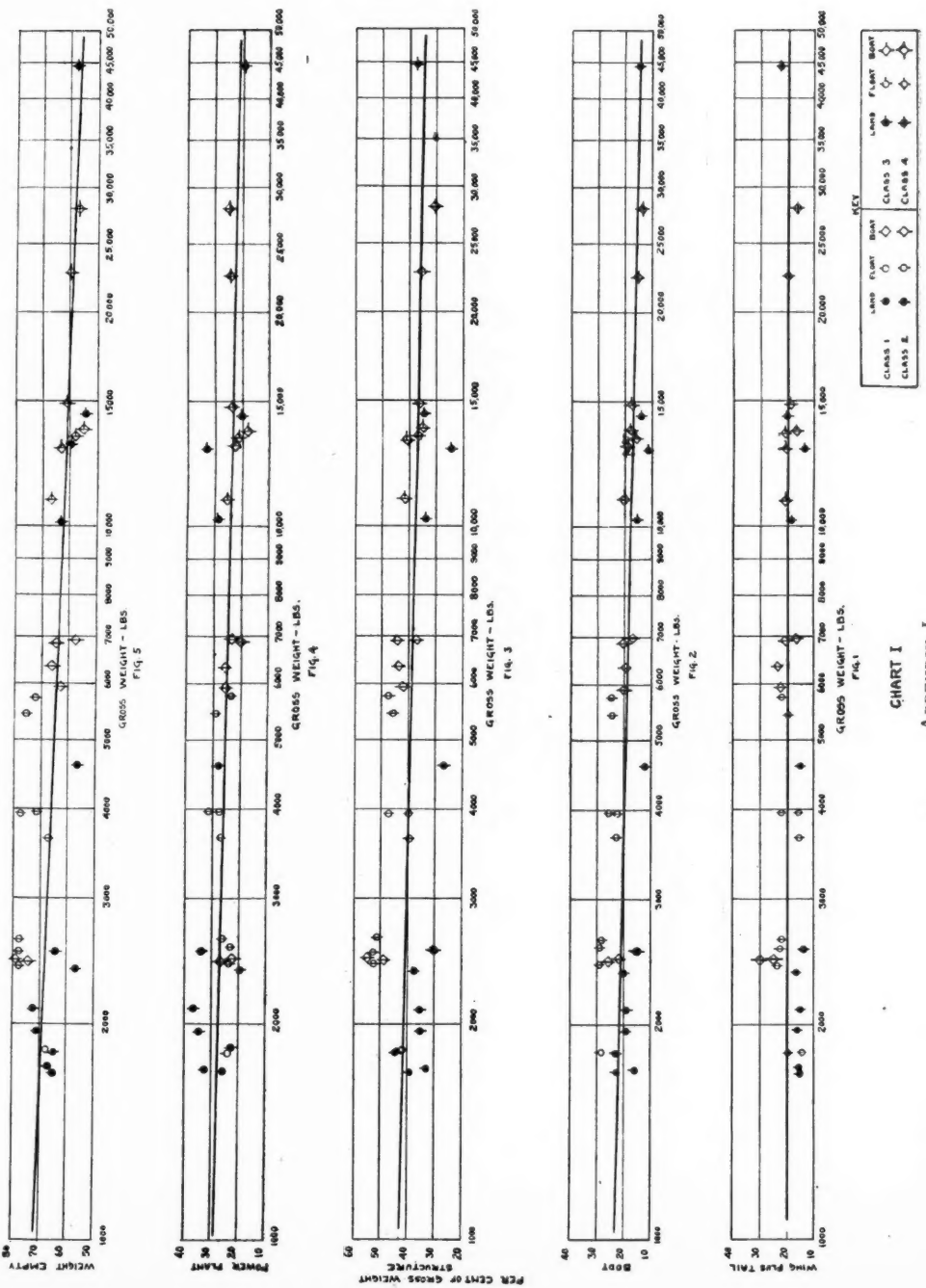


CHART I

APPENDIX I.

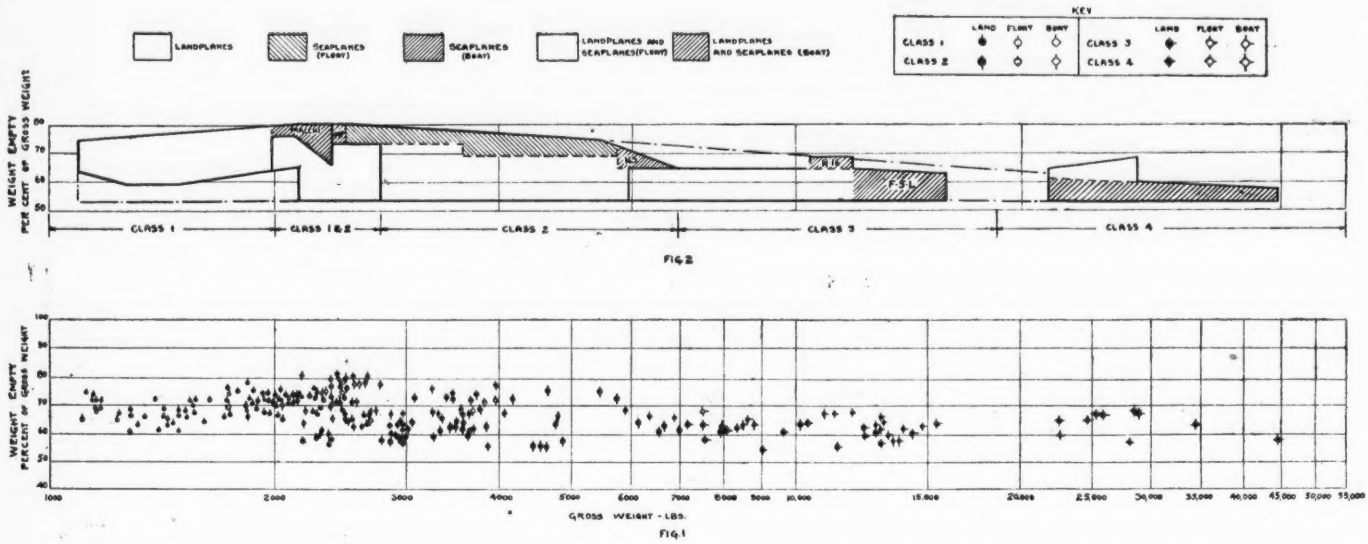


CHART II

APPENDIX I.

Fig. 4 is a plot of power plant weight with a mean line showing a downward trend, indicating that as size increases the per cent. power plant weight decreases. This seems reasonable as the large machines are not designed for great speed and the power is more nearly in proportion to gross weight than in the smaller machines which are generally considerably over-powered.

Fig. 5 is a plot of weight empty or structure plus power plant. The mean line drawn through the points indicates that as the size increases the percentage useful load increases, but only slightly.

To throw more light on this most important indication of a trend in design, Chart II., Fig. 1, has been prepared to include similar data for some 200 machines of all types. It is confirmed by this more comprehensive chart that, as before, the weight empty in percentage of the gross weight decreases slightly with size, leaving a larger percentage of useful load. There is a distinct trend established, but the most interesting feature is the insignificance of the advantage of mere size.

This chart was examined in order to discover any segregation by types. Such segregation is shown graphically in Fig. 2, where the heavy outlines represent the classes.

It will be noted that Class 1 (single-seaters) and Class 2 (two-seaters) overlap between 2,000 and 2,700lbs. It was impossible to distinguish between the land planes and float seaplanes in Class 1, but boat seaplanes are in a group (Macchi) by themselves.

In the case of Class 2 (two-seaters) all seaplanes are segregated in the upper part of the chart, showing that for gross weights between 2,000lbs. and 7,000lbs. the seaplanes appear to have a smaller percentage of useful load.

Class 3 (multi-engined 7,000lbs. to 18,000lbs.) shows how the F.5, which is an improvement and development of the H.16 flying boat, carries a greater load.

To summarise, it may be concluded that the lower limit of percentage weight empty so far realised by successful designs is about 53 per cent. It may also be concluded that in large sizes there is no superiority of land planes over seaplanes as weight carriers. Some advantage ought to lie, on the contrary, with the large seaplane on account of the higher permissible landing speed, and because the weight of hull decreases slightly more as the gross weight increases than does the landing gear and body of a land plane. Unfortunately, there is not sufficient data available for giant planes finally to prove or to disprove this much discussed point.

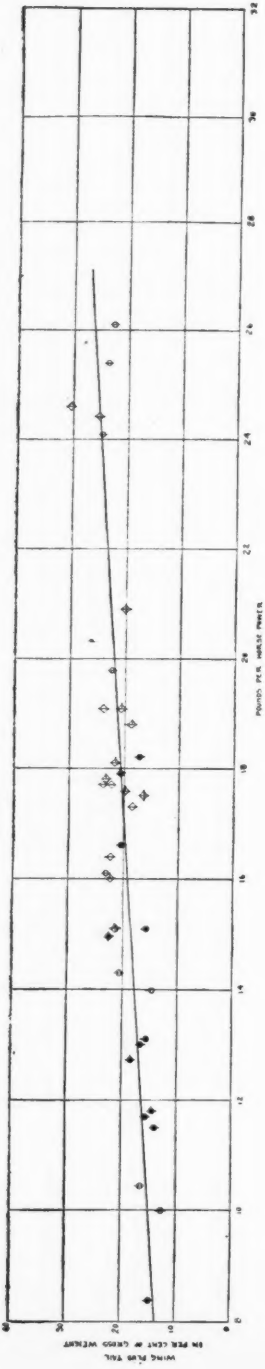
Chart III. shows the relation between these same group weights and the power loading or pounds per horse-power. There is a large range of loading, but the points lie thickest between 12 and 18 pounds per horse-power, the high speed airplanes lying below 12 and the low speed and training machines lying above 18.

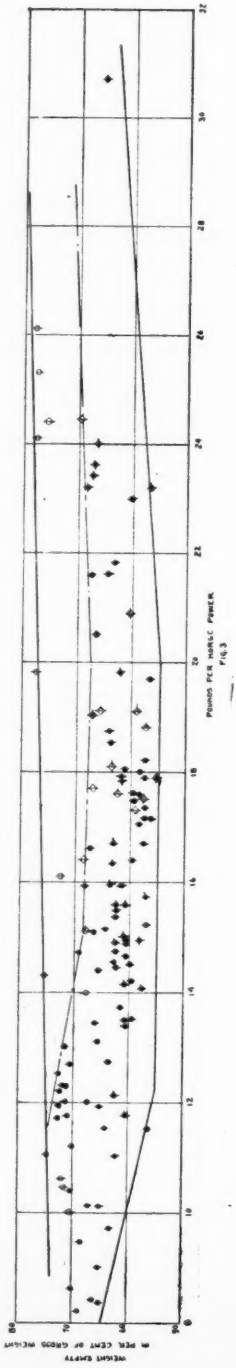
In Fig. 1 it appears that as the power loading increases, the per cent. power plant weight decreases, the lower limit being practically constant at 20 per cent. from 15 pounds per horse-power up.

Fig. 2 brings out a rise in percentage structure with high power loading, due probably to the larger wing surface necessary on account of reduced speed. The large percentage of structural weight in the training plane region (22 to 26 pounds per horse-power) is noteworthy.

Considering Figs. 1 and 2 together, it is evident that seaplanes have, in general, a lower percentage power plant and a higher percentage structure than land planes. This, of course, indicates a poorer performance. As the weight of the wing surface is most affected by the power and generally represents about 50 per cent. of the structural weight, Fig. 4 (wing and tail weight) was plotted to show this increase more clearly.

Fig. 3 (per cent. weight empty) is interesting, in that it seems to indicate,


WING PLUS TAIL
IN PER CENT OF GROSS WEIGHT
POUNDS PER HORSE POWER
FIG. 4


WEIGHT EMPTY
IN PER CENT OF GROSS WEIGHT
POUNDS PER HORSE POWER
FIG. 3

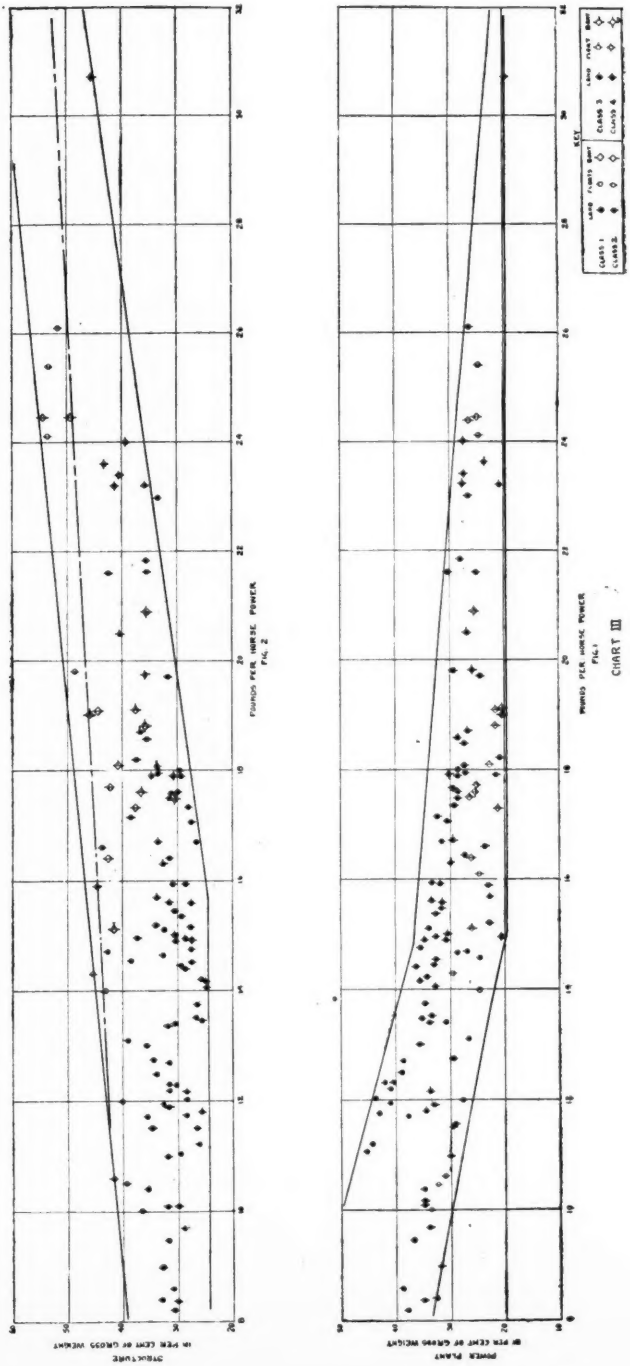
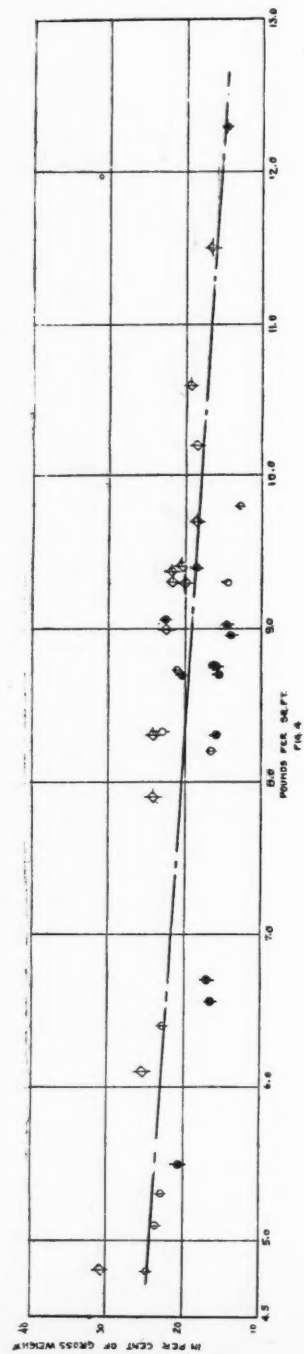


CHART III

APPENDIX I.


WEIGHT EMPTY
IN PER CENT OF GROSS WEIGHT
POUNDS PER SQ.FT.
FIG.3
WING PLUS TAIL
IN PER CENT OF GROSS WEIGHT
POUNDS PER SQ.FT.
FIG.4

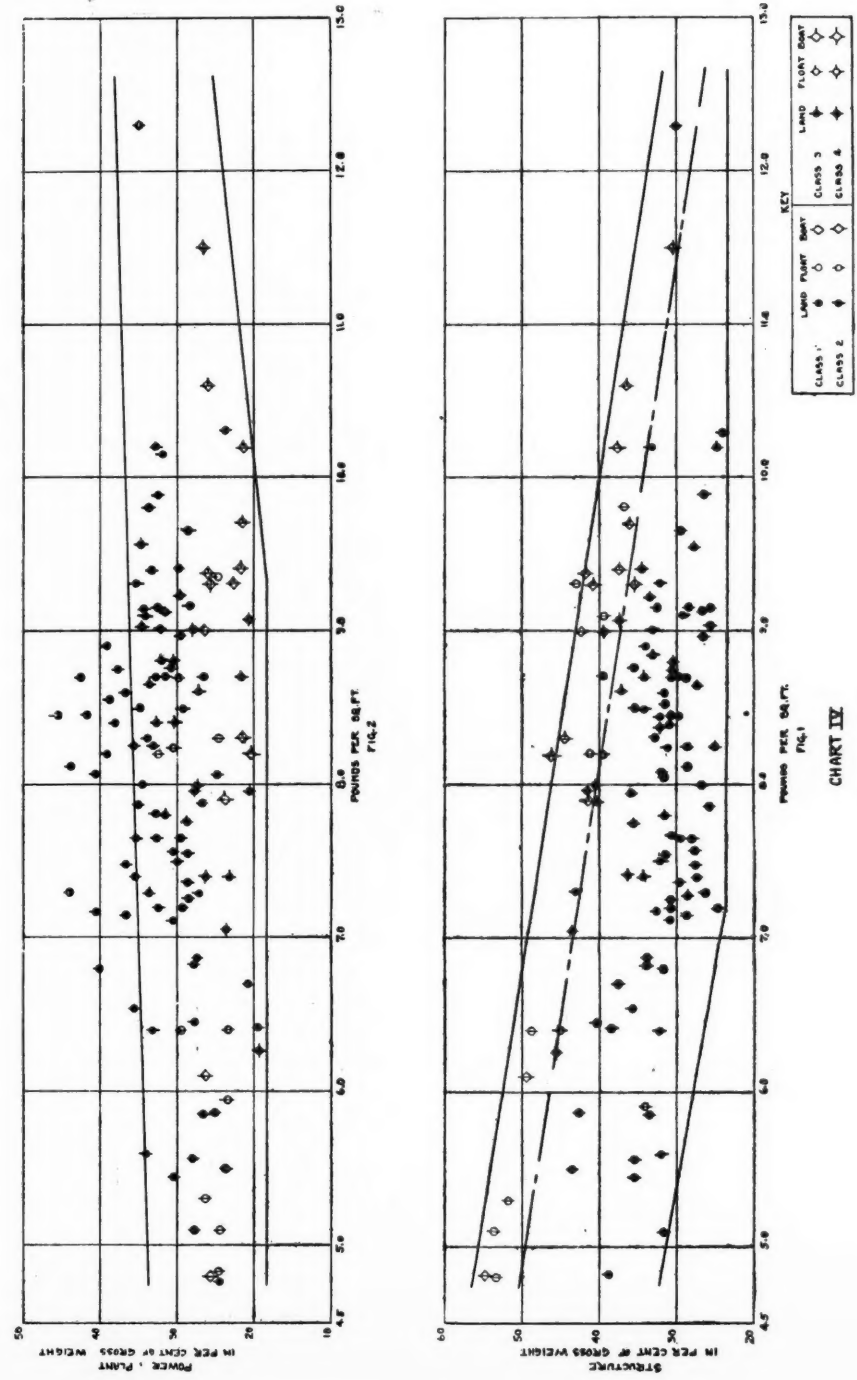


CHART IV

APPENDIX I.

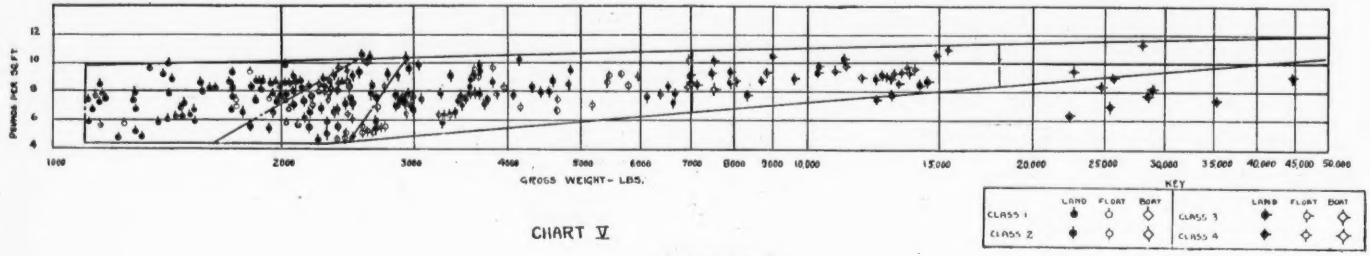


CHART V

APPENDIX I.

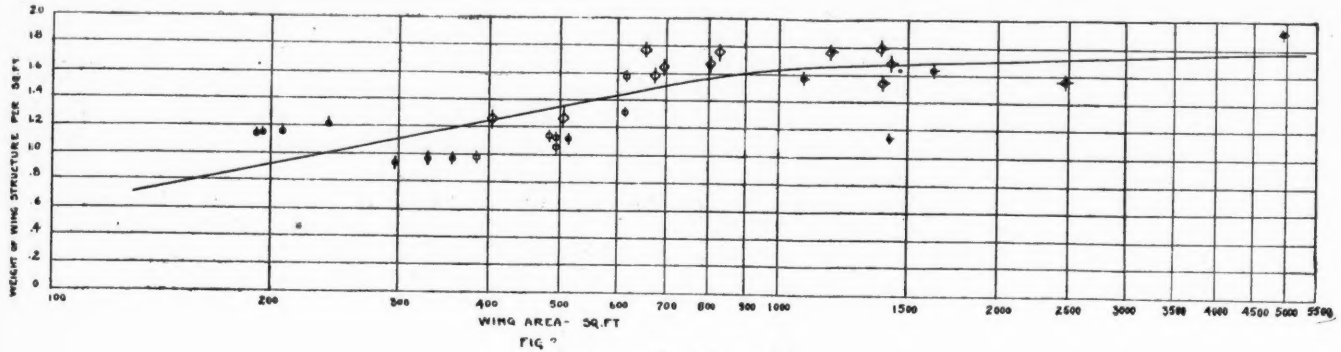


FIG ?

APPENDIX I. CHART VI.

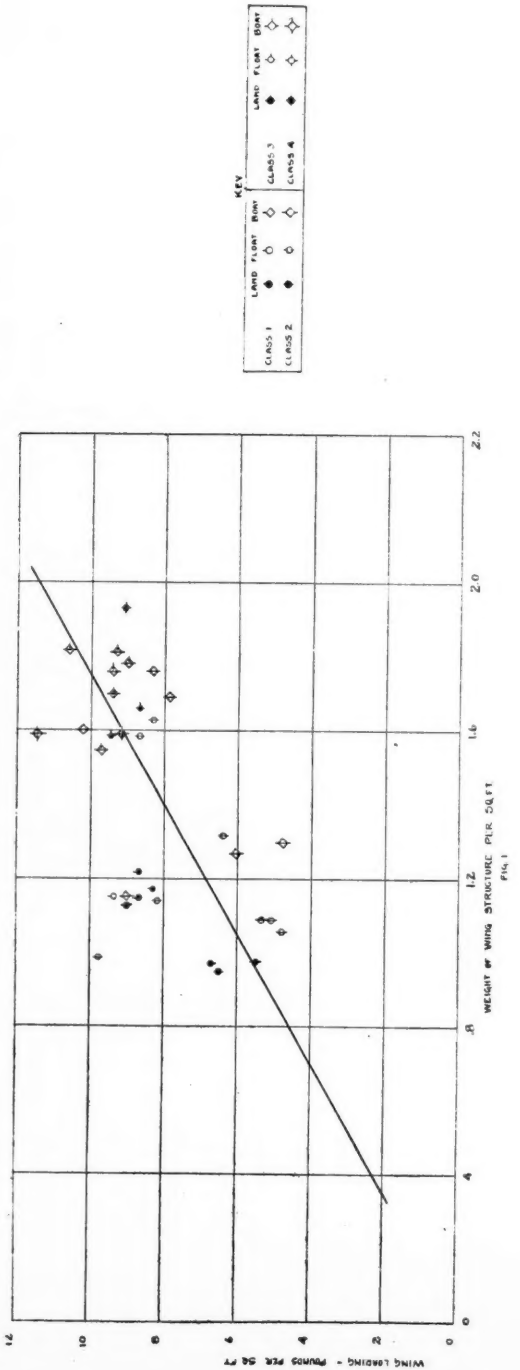


FIG. 1

CHART VI

APPENDIX I.

neglecting training airplanes and certain other abnormal airplanes in the upper part of the plot, that the minimum light weight is obtained for a power loading between 14 to 18.

In general, it would be expected that, if the group weights of Chart III. were plotted against pounds per square foot instead of pounds per horse-power, the envelopes should slope in the reverse direction. Chart IV. confirms this contention although not conclusively.

Fig. 1 shows that the per cent. structure decreases with increase of loading, and is supported by Fig. 4, which shows a decrease of wing and tail weight with increase of wing loading.

Fig. 3 (per cent. weight empty *vs* pounds per sq. ft.) shows, as expected, a decrease with high wing loading.

Chart V. shows how designers have selected the wing loading for machines of different sizes. There is no marked segregation between seaplanes or land planes in Classes 1, 2 and 3, but in Class 4 it will be noted that the boat type seaplanes have higher wing loadings than corresponding land machines. The wing loading is determined more by the allowable maximum landing speed than any other consideration. This chart is principally of interest in showing the upward tendency of the loading in the case of boat seaplanes as size increases, and brings out the principal advantage of the large flying boat.

Fig. 1, Chart VI. shows the relation between the wing weight per square foot (including struts and wires) and the unit loading. The result is not very conclusive, on account of the meagreness of the data, but the chart is of interest if for no other reason than to show the wide variation of results caused by different types of construction.

The tendency is for the unit weight of wing to increase at a greater rate than the loading, but reduction in factor of safety and change in the type construction for larger machines balances this tendency and keeps the rate of increase of wing weight substantially proportional to the increase of loading.

Fig. 2, Chart VI., shows, in a general way, the trend of design in regard to wing weights. The unit wing weight, including struts and wires, but excluding tail surfaces, increased rapidly with wing area up to about 1,300 sq. ft., but at about this point we have a decrease in factor of safety and the introduction of hollow struts and spars. Probably for these reasons, the unit wing weight does not continue to increase and for especially refined designs may even take a drop. Again at about 2,500 sq. ft., we expect the introduction of latticed construction for wing beams and ribs, and again a check in the rising trend of unit wing weights. As a result, the unit weight of wings for large machines need not increase materially provided the type of construction is changed to take advantage of opportunities for more economical use of material. In particular, the very large machines, if given a triplane wing arrangement, should show a reduction in unit wing weight, especially where latticed metal construction is introduced.

The symbols in the first column of Tables I., II., III. and IV. denote the class and type of each aeroplane in accordance with the following scheme :—

	Land.	Float.	Boat.
Class 1	1a	1b	1c
Class 2	2a	2b	2c
Class 3	3a	3b	3c
Class 4	4a	4b	4c

The data in these tables were obtained from official publications of the British, French, Italian, German and United States Governments, and technical publications.

TABLE I.

Class.	Name.	Gross wt. lbs.	Area sq.ft.	Lbs. / sq. ft.	Lbs. / H.P	Per cent. of Gross Weight. Wt. empty.	Struct-ure.	Power plant.	Wing and tail.	Body.
1a	Hanriot	1709	195	8.7	13.1	65.6	39.0	26.6	15.5	23.5
1a	Avro Spider... ...	1734	208	8.3	15.1	66.2	32.4	33.8	15.9	16.5
1b	Hanriot	1827	195	9.3	14.0	67.9	43.0	24.9	14.5	28.5
1a	S.E.-5A	2100	240	8.7	11.7	72.9	35.1	37.8	15.7	19.4
2a	Avro 504K	1829	330	5.5	16.6	67.3	43.8	23.5	20.1	23.7
2a	VE-7	1958	299	6.5	13.0	71.4	35.7	35.7	16.6	19.1
2a	Sopwith (1½) ...	2377	353	6.7	18.2	57.8	37.1	20.7	17.0	20.1
2b	N-9	2412	496	4.8	24.1	77.9	53.2	24.7	24.5	28.7
2c	MF	2448	401	6.1	24.4	75.6	49.5	26.1	25.3	24.2
2c	Model 40	2461	508	4.8	24.6	79.6	54.4	25.2	30.3	24.1
2a	M-8	2517	204	12.3	8.4	65.0	30.0	35.0	14.9	15.1
2b	Aero. 39B	2543	494	5.1	25.4	77.6	53.3	24.3	23.6	29.7
2b	Aero. 39A	2618	494	5.3	26.1	78.0	51.7	26.3	22.9	28.8
2b	HA	3805	386	9.8	10.0	70.4	36.9	33.5	12.7	24.2
2b	R-6	3964	613	6.4	19.8	77.7	48.5	29.2	22.6	25.9
2b	HA	3975	485	8.2	10.5	71.7	39.6	32.1	16.4	23.2
2a	US D-9	4000	514	9.0	11.5	56.2	26.6	29.6	14.0	12.6
2b	D-4	5418	620	8.7	14.3	75.2	45.5	29.7	20.6	24.9
2b	N-1	5795	695	8.3	16.1	72.9	48.4	24.5	23.0	25.4
2c	HS-1 L	5902	653	9.0	16.4	68.9	42.4	26.5	22.3	20.1
2c	HS-2 L	6373	803	7.9	17.7	66.9	41.9	25.0	23.3	18.6
2c	HS-3	6900	824	8.3	19.1	65.9	44.8	21.1	23.9	20.9
2c	Sperry	6916	678	10.2	17.3	58.9	37.7	21.2	18.4	19.3
3a	M.B.T.	10168	1080	9.4	12.7	64.0	34.2	29.8	18.7	15.5
3c	H-16	10900	1164	9.4	15.1	67.9	41.9	26.0	21.4	20.5
3a	Caproni	12810	1420	9.0	11.8	60.2	25.7	34.5	14.4	11.3
3c	F-5-L	13000	1397	9.3	18.1	63.6	40.8	22.8	21.4	19.4
3c	F-3	13400	1425	9.4	19.1	59.1	37.2	21.9	20.5	16.7
3c	F-6-L	13514	1397	9.7	18.8	57.4	36.0	21.4	18.4	17.6
3a	Handley Page ..	14374	1648	8.7	17.9	55.6	34.4	21.2	20.3	14.1
3c	F-5-L	14844	1397	10.6	17.6	62.3	36.4	25.9	19.4	17.0
4c	NC-2	22600	2441	9.3	20.9	60.6	35.5	25.1	20.0	15.5
4c	NC-4	28000	2441	11.5	17.5	57.1	30.5	26.6	16.1	14.4
4a	Tarrant Tabor ...	44862	4950	9.1	15.0	58.2	37.6	20.6	22.6	15.0

TABLE II.

Class.	Name.	Gross wt. lbs.	Area. sq. ft.	Lbs. / sq. ft.	Lbs. / H.P.	Per cent. of Gross Weight. Wt. empty.	Struct-ure.	Power plant
1a	Nieuport XXI. ...	1179	161	7.3	14.7	70.0	43.0	27.0
1a	Da	1275	180	7.1	13.4	60.2	30.1	30.1
1a	Db	1400	153	9.2	14.7	60.9	32.7	28.2
1a	Morane A1	1429	140	10.2	8.4	65.0	33.0	32.0
1a	Dc	1720	254	6.8	12.3	71.4	31.4	40.0
1a	Dd	1855	254	7.3	11.2	70.0	26.0	44.0
1a	De	1865	221	8.5	11.0	74.9	29.8	45.1

TABLE II. (*continued*).

Class.	Name.	Gross wt. lbs.	Area. sq. ft.	Lbs. / sq. ft.	Lbs. / H.P.	Per cent. of Gross Weight. Wt. empty.	Struct-ure.	Power plant.
1a	Spad XIII. ...	1887	226	8.3	8.6	70.0	31.0	39.0
1a	Df	1960	225	8.7	11.8	71.0	28.6	42.4
1a	Dg	1990	278	7.2	12.0	72.8	32.4	40.4
1a	Dh	2000	247	8.1	12.0	71.7	28.2	43.5
1a	Di	2020	239	8.5	12.3	71.7	30.3	41.4
1a	Albatros	2037	226	8.9	12.5	73.0	34.0	39.0
1a	Dk	2101	246	8.6	12.7	70.3	31.5	38.8
1a	Dl	2260	280	8.1	12.2	72.3	31.8	40.5
1a	Albatross	2425	288	8.4	8.2	69.0	31.0	38.0
2b	Sopwith-1	2041	344	5.9	15.2	57.0	34.0	23.0
2b	F B A Type C ..	2070	322	6.4	15.9	68.0	45.0	23.0
2a	Ba	2300	449	5.1	16.4	59.7	31.8	27.9
2b	Spad	2335	282	8.3	10.6	72.0	41.0	31.0
2a	Ca	2361	258	9.1	14.2	59.6	25.5	34.1
2a	Bb	2390	438	5.5	21.6	65.7	35.5	30.2
2a	Cb	2498	348	7.2	14.4	65.2	28.7	36.5
2a	Hanriot	2507	274	9.1	9.7	63.0	29.0	34.0
2a	Bc	2680	457	5.9	21.6	67.4	42.4	25.0
2a	AR Type I.	2756	484	5.6	13.4	66.0	32.0	34.0
2a	Cc	2775	297	9.1	16.7	57.8	26.4	31.4
2a	Cd	2840	370	7.7	17.4	57.4	28.0	29.4
2a	Ce	2870	397	7.2	17.6	59.4	30.2	29.2
2a	Spad XX.	2877	312	9.0	9.0	65.0	33.0	32.0
2a	Cf	2900	384	7.6	17.5	59.6	31.1	28.5
2a	Cg	2920	402	7.3	17.6	58.9	30.4	28.5
2a	Ch	2945	388	7.6	17.1	58.2	27.6	30.6
2a	Salmson 2	2956	388	7.6	11.0	62.0	32.0	30.0
2a	Ci	2970	411	7.2	17.2	56.6	24.3	32.3
2a	Ck	2970	308	9.7	17.9	57.9	29.3	28.6
2a	Cl	2980	438	6.8	17.9	61.7	33.9	27.8
2a	Cm	2990	405	7.4	18.0	58.4	29.8	28.6
2a	Cn	3000	435	6.9	18.1	61.2	33.8	27.4
2a	Co	3260	415	7.8	14.5	59.9	27.4	32.5
2a	Breguet 14 A ...	3344	527	6.4	11.9	65.0	32.0	33.0
2a	Cp	3360	367	9.2	15.0	60.7	28.3	32.4
2a	Sea	3400	398	8.6	8.8	65.0	30.0	35.0
2a	Cq	3415	461	7.4	14.7	62.5	27.2	35.3
2a	Cr	3450	450	7.7	15.4	62.4	29.6	32.8
2a	Cs	3500	466	7.5	15.2	64.1	27.7	36.4
2a	Ct	3575	433	8.3	15.9	61.4	28.4	33.0
2a	Cu	3580	414	8.7	15.5	62.2	30.8	31.4
2a	Cv	3620	460	7.9	13.5	60.8	25.8	35.0
2a	Cw	3630	366	9.9	13.5	59.4	26.2	33.2
2a	Le Pere	3655	393	9.3	10.1	67.0	32.0	35.0
2a	Cx	3680	460	8.0	13.7	61.1	26.6	34.5
2b	DD	3750	568	6.8	18.8	63.0	44.0	19.0
2a	Cy	3820	438	8.7	14.5	62.3	29.4	32.9
2a	Breguet	4090	527	7.7	10.1	65.0	30.0	35.0
2a	Ja	4150	400	10.3	18.5	51.8	24.0	27.8
2a	Jb	4430	546	8.1	19.7	56.4	31.7	24.7
2a	Caudron R-11 ...	4839	538	8.5	11.5	64.0	35.0	29.0

TABLE II. (*continued*).

Class.	Name.	Gross wt. lbs.	Area. sq. ft.	Lbs. / sq. ft.	Lbs. / H.P.	Per cent. of Gross Weight. Wt. empty.	Struct-ure.	Power plant.
2a	Ga	6150	792	7.8	18.6	63.9	35.5	28.4
2a	Gb	6560	797	8.3	14.2	60.5	25.0	35.5
2a	Gc	6670	915	7.3	12.2	62.1	28.5	33.6
2a	Gd	6700	849	7.9	20.5	66.9	40.1	26.8
2a	Ge	7000	809	8.7	15.6	60.9	27.6	33.3
3a	Gf	7180	853	8.4	16.0	63.3	30.9	32.4
3a	Gg	7500	816	9.2	16.7	63.0	33.5	29.5
3a	Gh	7540	740	10.2	14.1	57.6	24.7	32.9
3c	Tellier	7600	928	8.2	19.0	67.0	47.0	20.0
3a	Gi	7980	835	9.6	14.9	62.4	27.9	34.5
3a	Gk	7980	915	8.7	14.9	60.6	30.2	30.4
3a	Gl	8050	915	8.8	15.0	61.0	30.8	30.2
3a	Gm	8370	1072	7.8	15.6	62.5	31.3	31.2
3a	Caproni	8752	1023	8.8	16.3	63.0	33.0	30.0
3a	Voisin E 87 ...	12566	1679	7.4	15.7	57.0	34.0	23.0
3a	Handley Page ...	13390	1539	8.6	18.7	64.0	37.0	27.0
4a	Ra	22600	3570	6.3	30.7	65.1	45.5	19.6
4a	Handley Page ...	24989	2992	8.4	17.9	62.0	32.0	30.0
4a	Rb	25300	3570	7.1	23.6	67.0	43.2	23.8
4a	Rc	25800	2860	9.0	24.0	66.6	39.5	27.1
4a	Rd	28600	3570	8.0	23.2	68.9	41.3	27.6
4a	Re	28800	3570	8.1	23.4	67.3	40.1	27.2
4a	S. Schukert ...	35274	4789	7.4	19.8	62.0	36.0	26.0

TABLE III.

Class.	Name.	Gross wt. lbs.	Area. sq. ft.	Lbs. / sq. ft.	Lbs. / H.P.	Per cent. wt. empty.
1a	Macchi M 16A	562	122	4.6	5.9	62.6
1a	Macchi M 16G	562	122	4.6	7.9	60.6
1a	SA-2	810	156	5.2	14.7	64.2
1a	Ordnance E-C	1117	190	5.9	13.9	74.8
1a	Macchi M-14	1135	172	6.6	12.7	73.8
1a	Standard E-1	1144	153	7.5	14.3	72.4
1a	Gabardini	1150	160	7.2	12.8	71.1
1a	Macchi Mi 13	1150	140	8.2	12.8	69.2
1a	Morane S-3OEZ ...	1157	145	7.8	8.5	77.1
1a	Morane S-3OEv ...	1157	145	7.8	12.3	77.1
1a	Bristol Scout	1159	204	5.7	14.5	68.1
1a	Nieuport 24	1210	161	7.5	9.3	65.0
1a	Sopwith Pup	1225	254	4.8	14.6	64.2
1b	Beards N1A	1238	219	5.7	14.8	66.7
1a	Macchi Ni	1270	—	7.9	10.5	68.6
1a	Macchi HD	1270	—	6.9	10.5	66.9
1a	Sopwith Pup	1297	252	5.2	12.4	66.0
1a	Morse S4-C	1373	235	5.9	17.2	71.1
1a	Macchi M14	1412	—	7.9	11.8	68.8
1a	Sopwith Camel	1422	231	6.2	10.4	62.5

TABLE III. (*continued*).

Class.	Name.	Gross. wt. lbs.	Area. sq. ft.	Lbs. / sq. ft	Lbs. / H.P.	Per cent. wt. empty.
1a	Nieuport 24	1442	145	9.9	8.5	64.0
1a	Sopwith Camel	1453	231	6.3	11.6	63.9
1a	Sopwith Camel	1471	231	6.4	9.8	65.4
1a	Vickers FB-19	1478	211	7.0	11.6	60.5
1a	DH-5	1492	211	7.1	11.8	67.5
1a	Sopwith Camel	1523	233	6.6	10.2	63.5
1a	Sopwith Triplane ...	1543	257	6.0	12.4	71.3
1a	Spad 7-Cl	1553	194	8.1	9.1	70.9
1a	Spad 18	1560	194	8.1	9.1	71.0
1a	Nieuport 28	1563	181	8.4	8.8	66.8
1a	Hanriot	1605	195	8.3	12.3	63.6
1a	Spad	1632	200	8.2	10.9	71.7
1b	Sopwith Camel	1721	231	7.5	13.7	68.0
1b	Sopwith Baby	1742	245	7.1	13.9	73.3
1a	Sopwith Snipe	1775	270	6.6	7.8	74.0
1a	Spad 13 C	1820	224	8.5	8.3	69.2
1b	Hamble Baby	1946	256	7.6	17.1	71.3
1a	Spad CA1	1947	222	8.6	9.2	66.4
1a	A1 Ansaldo	1950	—	8.6	8.9	72.3
1a	SE-5A	1958	247	7.9	9.3	71.5
1a	Vickers MVT	1970	231	8.5	8.9	73.0
1a	SE-5	1980	249	8.0	9.8	73.5
1a	Sopwith Dolphin ...	2000	262	7.7	9.5	69.5
1a	Sopwith Snipe	2020	270	7.5	8.9	65.4
1a	Morse MB-3	2037	250	8.2	6.0	64.3
1a	Spad 17Cl	2077	222	9.1	6.9	73.0
1a	BE-12	2104	371	5.7	13.2	73.0
1a	Ansaldo SVA-4	2130	260	8.2	9.7	71.5
1a	Ansaldo SVA-6	2150	260	8.3	9.8	71.8
1c	Macchi P.B.	2183	313	7.0	13.6	80.1
1a	Salmson	2264	258	8.6	9.0	67.7
1a	Martinsyde F-4	2269	330	7.0	7.5	75.4
1a	Sopwith Snipe	2271	269	8.9	10.0	58.5
1c	Macchi M-5	2280	—	8.1	12.0	73.7
1c	Macchi M-5	2300	—	7.3	12.1	74.0
1a	Spad 21	2309	253	8.9	7.3	73.1
1a	Sopwith Bomber ...	2342	350	6.7	18.8	56.0
1c	Macchi M-7	2380	—	8.5	9.6	69.8
1b	Ansaldo (1SVA) ...	2385	—	9.7	11.6	79.4
1c	Macchi AS	2390	—	8.6	12.6	70.0
1b	Ansaldo (1SVA) ...	2430	—	9.2	11.9	79.6
1a	Martinsyde F-3	2446	338	7.2	8.5	76.0
1a	Martinsyde	2458	410	6.0	14.5	73.0
1a	Martinsyde Cl	2465	332	7.4	7.8	69.5
1a	Nieuport Cl	2532	266	9.5	7.3	70.4
1a	Ansaldo A-5	2620	322	8.1	9.1	66.1
1a	Spad H-20-Cl	2660	312	8.3	8.4	63.4
2a	Macchi Ni 18	1371	194	7.1	15.2	69.5
2a	Caudron AER	1610	290	5.5	17.9	61.0
2a	JN-4D	1920	353	5.4	21.3	74.5
2a	Vickers-Terni	1965	602	3.3	20.6	72.0

TABLE III. (*continued*).

Class.	Name.	Gross wt. lbs.	Area. sq. ft.	Lbs. sq. ft.	Lbs. H.P.	Per cent. wt. empty.
2a	Ansaldo SVA2	2030	236	8.6	10.0	75.5
2a	Vickers-Terni	2060	602	3.4	18.7	63.5
2a	VE-7	2090	292	7.2	11.6	72.2
2a	Vickers-Terni	2100	602	3.5	18.3	67.0
2a	Ansaldo SVA9	2130	289	7.4	10.5	71.5
2a	JN-4H	2145	353	6.1	14.3	74.4
2a	VE-7 G	2200	292	7.5	12.2	68.6
2a	Aeromarine	2220	494	4.5	22.2	74.3
2a	VE-7-GF	2300	292	7.9	12.8	69.6
2a	Ansaldo SVA10	2390	289	8.2	10.8	67.5
2b	Boeing	2455	495	5.0	24.6	79.0
2a	Ansaldo SVA10... ...	2460	289	8.4	9.9	68.5
2c	Model F	2460	387	6.4	24.6	75.6
2b	N-9	2550	488	5.2	17.0	80.0
2b	Type LS	2570	251	10.2	8.6	70.6
2b	N-9 (Mod.)	2663	490	5.5	17.7	80.1
2a	JN-6 HB	2687	353	7.6	19.9	66.9
2b	Type AS	2695	386	7.0	9.0	66.3
2b	N-9	2750	496	5.5	18.3	77.8
2a	Sit Voisin	2760	580	4.7	14.5	72
2c	Sia-S13	2840	370	7.6	11.3	69.1
2a	Bristol USB-2	2848	406	7.0	9.8	63.0
2a	Bristol	2910	403	7.2	9.7	63.3
2c	Macchi L-3	2980	495	6.0	15.7	66.7
2c	Macchi L-3	2980	495	6.0	15.1	66.5
2a	Bristol USXB	2994	406	7.4	10.0	67.1
2c	SIA-S8	3010	495	6.1	13.7	65.0
2a	SAML-S2	3080	420	7.35	11.8	73
2c	Zari FBA	3100	450	6.9	16.3	66.0
2a	SAML 6	3140	485	6.5	12.1	70.3
2c	SIA-S8	3157	495	6.4	16.6	66.7
2c	Macchi M-8	3170	430	7.3	16.6	68.5
2c	SIA-FBA	3220	452	7.1	16.9	67.5
2c	SIA-S8	3220	495	6.5	16.1	68.0
2c	Tellier	3225	506	6.4	16.1	76.6
2a	R-4	3272	545	6.0	16.4	68.0
2a	Savi. SP-2	3360	720	5.2	14.4	73.6
2a	Pomilio PE	3400	495	6.85	11.3	73.8
2a	Ansaldo A300	3460	—	—	11.56	73.0
2a	Pomilio PD	3480	495	7.1	13.4	74.6
2a	DH-4	3582	440	8.1	10.0	66.7
2b	HA	3680	387	9.5	9.7	72.8
2a	SIA-R2	3710	500	7.4	12.4	74.5
2a	SIA-SP3	3730	645	5.8	14.4	73.4
2a	Breguet	3750	526	7.1	12.5	68.2
2c	SIAI-S9	3840	512	7.5	12.8	68.3
2c	DD.	3860	491	7.9	19.3	56.6
2c	Macchi M-9	3880	495	7.8	12.9	68.5
2b	R-9	4184	613	6.8	20.9	72.9
2a	USD-9A	4322	514	8.4	12.0	65.1
2a	Pomilio VL-12	4540	580	8.0	11.7	56.4

TABLE III. (*continued*).

Class.	Name.	Gross wt. lbs.	Area. sq. ft.	Lbs. / sq. ft.	Lbs. / H.P.	Per cent. wt. empty.
2b	R-6-L	4634	613	7.6	12.9	75.8
2b	D-9	4670	718	6.5	12.3	63.7
2a	USD-9A	4872	514	9.5	13.5	57.8
2c	Levi Le Pen	5180	739	7.0	18.5	58.9
2c	SIAI-S12	5210	562	9.3	10.9	66.2
2b	R-6-L	5662	613	9.3	15.7	62.1
2a	Caproni CA 2	6400	1045	6.1	19.5	66.0
2a	Caproni CA 2	6710	1045	6.3	16.0	66.5
2a	SIA-BR	7000	756	9.2	16.2	68.2
3c	TF	8846	930	9.5	14.8	63.0
3a	DH-10A	9000	851	10.6	12.5	53.9
3a	Martin Bomber	9663	1070	9.0	14.4	60.7
3a	MT	11148	1070	10.4	14.0	52.2
3c	H-16-1	11168	1124	9.9	15.5	66.2
3c	H-16-2	11875	1306	9.1	18.0	68.9
3c	F-5-L	15430	1397	11.1	21.5	63.2
3c	Bast. PRB	16150	2155	7.5	16.1	59.0

TABLE IV.

Class.	Name.	Gross wt. lbs.	Area. sq. ft.	Lbs. / sq. ft.	Unit wt. wings.
1a	Hanriot	1709	195	8.7	1.15
1a	Avro Spider	1734	208	8.3	1.17
1b	Hanriot	1827	195	9.3	1.15
1a	S.E.-5 A	2100	240	8.7	1.22
2a	Avro 504 K	1829	330	5.5	.98
2a	VE-7	1958	299	6.5	.95
2a	Sopwith (1½)	2377	353	6.7	.97
2b	N-9	2412	496	4.8	1.06
2c	MF	2448	401	6.1	1.27
2c	Model 40	2461	508	4.8	1.30
2b	Aero. 39 B	2543	494	5.1	1.09
2b	Aero. 39 A	2618	494	5.3	1.09
2b	HA	3805	386	9.8	.99
2b	R-6	3964	613	6.4	1.32
2b	HA	3975	485	8.2	1.14
2a	US D-9	4600	514	9.0	1.13
2b	D-4	5418	620	8.7	1.59
2b	N-1	5795	695	8.3	1.63
2c	HS-1-L	5902	653	9.0	1.78
2c	HS-2-L	6373	803	7.9	1.69
2c	HS-3	6900	824	8.3	1.76
2c	Sperry	6916	678	10.2	1.60
3a	M.B.T.	10168	1080	9.4	1.59
3c	H-16	10900	1164	9.4	1.76
3a	Caproni	12810	1420	9.0	1.15
3c	F-5-L	13000	1397	9.3	1.81
3c	F-3	13400	1425	9.4	1.70
3c	F-6-L	13514	1397	9.7	1.55
3a	Handley Page	14374	1648	8.7	1.66
3c	F-5-L	14844	1397	10.6	1.81
4c	NC-2	22600	2441	9.3	1.59
4c	NC-4	28000	2441	11.5	1.59
4a	Tarrant Tabor	44862	4950	9.1	1.93

APPENDIX II.*

METACENTRIC HEIGHT.

TABLE I.

CALCULATED METACENTRIC HEIGHTS.

Machine.	Weight. lbs.	Chord. ft.	Angle of Stabilizer to Wing.	Angle of Attack.	G_m. ft.	Remarks.
						U.S.N.—W.T.R. 117
SA-2	625	6.0	— 2.0	9	3.35	Eiffel—N.R.A.A.
Morane-Saulnier ...	1210	5.5	—	12	3.17	Technische Berichte B-III., h2
AEG-D1	1275	4.5	+ 0.25	4	5.00	
Boeing 2	1600	5.0	— 2.2	6	4.87	U.S.N.—W.T.R. 26
Farman (1912) ...	1610	6.1	—	10	6.78	Eiffel—N.R.A.A.
Curtiss JN-2	1800	5.0	— 3.5	2	9.35	N.A.C.A. Report 17
S.V.A.	1985	5.25	— 2.5	5	5.72	U.S. Army—A.T.R. 27
Boeing 1	2000	5.6	— 5.0	6	13.45	U.S.N.—W.T.R. 25
Thomas-Morse SH4..	2300	5.6	— 5.0	6	8.66	,, ,, 14
Curtiss N-9	2310	5.0	— 2.0	6	2.80	,, ,, 12
Sturtevant S4 ...	2650	7.0	— 5.0	4	7.45	,, ,, 10
Bristol Fighter ...	2680	5.5	— 1.75	3	8.03	U.S. Army—A.T.R. 25
Burgess S	2800	6.5	— 3.5	8	5.02	U.S.N.—W.T.R. 13
Le Pere Fighter ...	3055	5.5	— 0.1	2	3.15	U.S. Army—A.D.M. 479
USD-9A Bomber ...	4320	6.0	— 2.8	6	12.61	,, A.T.R. 2
N-1 (U.S.N.) ...	5500	6.75	— 4.0	8	6.00	U.S.N.—W.T.R. 49
Curtiss HS-1L ...	5500	6.3	— 5.5	9	7.18	,, ,, 62
Curtiss H-12 ...	8050	7.0	— 3.0	8	12.90	,, ,, 19
TF (U.S.N.)... ...	8850	9.0	— 2.0	10	10.77	,, ,, 136
F-5-L	13500	12.0	— 1.5	9	6.80	,, ,, 118
Handley Page ...	14425	10.0	— 1.5	6	11.95	Br.A.C.A. R. & M. 198
NC-1	22000	12.0	— 2.0	8	11.20	U.S.N.—W.T.R. 56
NC-TA	28000	12.0	— 1.0	8	27.40	,, ,, 56
TB (U.S.N.)... ...	60000	22.0	— 5.5	8	22.20	,, ,, 112
Verville-VCP1 ...	2425	5.5	— 0.5	4	3.84	U.S. Army—A.D.M. 409
Le Pere-USAP2 ...	2100	4.5	— 1.0	8	4.00	,, ,, 415
Triplane-GAX ...	9450	6.0	— 0.9	6	2.30	,, ,, 483

* I am indebted to my assistant, Lieut. W. S. Diehl, for help in the preparation of this Appendix.

TABLE II.

METACENTRIC HEIGHT.

EFFECT OF CHANGE IN ANGLE OF STABILIZER SETTING.

Machine.	Angle between Stabilizer and Wing Chord. β	Gm Feet	$\frac{\Delta Gm}{\Delta \beta}$	Horizontal tail surface in per cent. of wing area.	Remarks.
S4	— 3.2°	3.44		12.60	U.S.N.—W.T.R. 10
,, ...	— 5.0	7.45	2.20	12.60	
JN-2	— 3.5	6.21		10.38	N.A.C.A. 17
,, ...	— 5.0	8.44		10.38	Small tail, medium body
,, ...	— 7.0	11.14	1.45	10.38	
JN-2	— 2.0	5.80		11.52	Ditto
,, ...	— 3.5	9.34		11.52	Medium tail, medium body
,, ...	— 5.0	11.55	1.85	11.52	
JN-2	— 1.0	6.21		12.66	Ditto
,, ...	— 2.0	8.00		12.66	Large tail, medium body
,, ...	— 3.5	12.43	2.40	12.66	
Le Pere	— 1.0	9.17		12.90	
,, ...	0	6.76		12.90	
,, ...	+ 1.1	3.13		12.90	U.S. Army—A.D.M. 429
,, ...	+ 2.1	2.15		12.90	
,, ...	+ 3.0	0	2.35	12.90	
Verville	+ 0.5	2.63		12.20	
VCPI	0	3.09		12.20	U.S. Army—A.D.M. 409
,, ...	— 0.5	3.84		12.20	
,, ...	— 1.0	5.27	1.80	12.20	
USAP2	+ 0.5	3.21			
,, ...	— 0.5	2.98		No data	U.S. Army—A.D.M. 415
,, ...	— 1.0	4.00			
,, ...	— 1.5	4.30	1.35		
NC-1	— 3.0	14.35		13.10	Curtiss tests—large tail
,, ...	— 1.0	7.61	3.30	13.10	
NC-1	— 3.0	7.45		11.13	Ditto—medium
,, ...	— 1.0	2.30	2.50	11.13	
NC-1	— 3.0	5.31		10.72	Ditto—small
,, ...	— 1.0	1.43	22.9	10.72	
Bristol Fighter ...	+ .25	1.43		10.80	
,, ,, ...	— 1.75	4.75		10.80	U.S. Army—A.T.R. 25
,, ,, ...	— 3.5	6.15	1.35	10.80	

TABLE III.

METACENTRIC HEIGHT.

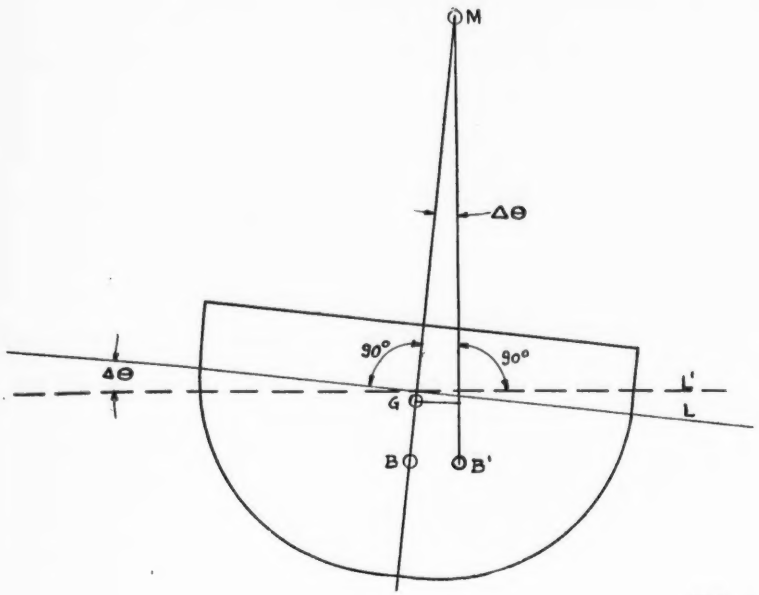
EFFECT OF CHANGE IN STABILIZER AREA.

Machine.	Horizontal Tail Area in per cent. of original area.	s/S.	Gm.	Remarks.
JN-2	90	10.38	6.24	N.A.C.A. Report 17.
	100	11.52	9.55	Stabilizer at — 3.5° to wing chord.
	110	12.66	12.00	$\Delta Gm/\Delta\,(s/S) = 0.29$.
NC-1	100	13.00	8.61	U.S.N.—W.T.R. 56.
	114	14.83	14.33	Stabilizer at — 4° to wing chord.
				$\Delta Gm/\Delta\,(s/S) = 0.39$.
NC-1	100	13.10	14.35	Curtiss tests.
	85	11.13	7.45	Stabilizer at — 3° to wing chord.
	81	10.72	5.31	$\Delta Gm/\Delta\,(s/S) = 0.46$.
NC-1	100	13.10	7.61	Curtiss tests.
	85	11.13	2.30	Stabilizer at — 1° to wing chord.
	81	10.72	1.43	$\Delta Gm/\Delta\,(s/S) = 0.31$.
N1	100	15.42	7.17	U.S.N.—W.T.R. 49.
	107	16.60	9.00	Stabilizer at — 4° to wing chord.
				$\Delta Gm/\Delta\,(s/S) = 0.31$.

TABLE IV.

FORE AND AFT MOVEMENT OF CENTRE OF PRESSURE WITH CHANGE IN ANGLE OF STABILIZER SETTING.

Machine.	Vector.	Stabilizer Setting Degrees β	Vector Location Feet.	Movement. Feet L.	Wing Chord Feet.	$\Delta L / \Delta \beta$
Le Pere	4°	— 1.0	6.15	— .24		
,, ...	,,	0	6.39	0	5.5	0.170
,, ...	,,	+ 1.1	6.53	+ .14		
,, ...	,,	+ 2.0	6.67	+ .28		
Bristol Fighter ...	4°	+ 0.25	6.32	0		
,, ,, ...	,,	— 1.75	5.92	— .40	5.5	.245
,, ,, ...	,,	— 3.30	5.44	— .88		
USD-9A	4°	— 1.0	7.40	0		
,, ...	,,	— 2.8	7.06	— .34	6.0	.165
,, ...	,,	— 4.5	6.50	— .56		
VGPI	4°	+ 0.5	—	—		
,, ...	,,	0	2.94	0	5.5	
,, ...	,,	— 0.5	2.87	— .07		.230
,, ...	,,	— 1.0	2.68	— .26		
Handley Page ...	4°	+ 2.2	1.92	+ .93		
,, ,, ...	,,	+ 1.0	1.38	+ .39		
,, ,, ...	,,	0	.99	0	10.0	.370
,, ,, ...	,,	— 1.0	.62	— .37		
,, ,, ...	,,	— 2.0	.24	— .75		
,, ,, ...	,,	— 3.0	—.04	— 1.03		
JN-2	4°	— 3.5	.67	0		
,, ...	,,	— 5.0	.75	— .08	5.0	.090
,, ...	,,	— 7.0	1.00	— .32		
JN-2	4°	— 2.0	.42	0		
,, ...	,,	— 3.5	.67	— .25	5.0	.130
,, ...	,,	— 5.0	.75	— .33		
JN-2	4°	— 1.0	.33	0		
,, ...	,,	— 2.0	.42	— .09	5.0	.135
,, ...	,,	— 3.5	.67	— .34		
NC-1	4°	— 1.0	.75	0	12.0	.450
,, ...	,,	— 3.0	1.65	— .90		
USAP2	4°	+ 0.5	.13	0		
,, ...	,,	— 0.5	.23	— .10	4.5	.170
,, ...	,,	— 1.0	.37	— .24		
,, ...	,,	— 1.5	.43	— .30		
TB	6°	— 5.5	0	— 3.05		
,, ...	,,	— 2.5	1.95	— 1.10	22.0	.650
,, ...	,,	— 1.5	2.60	— .45		
,, ...	,,	— 0.5	3.05	—		



W = TOTAL WEIGHT,

L, L' = WATER LINES UPRIGHT AND INCLINED.

B, B' = CENTERS OF BUOYANCY UPRIGHT AND INCLINED

Δθ ANGLE OF INCLINATION

M = METACENTER

G = CENTER OF GRAVITY

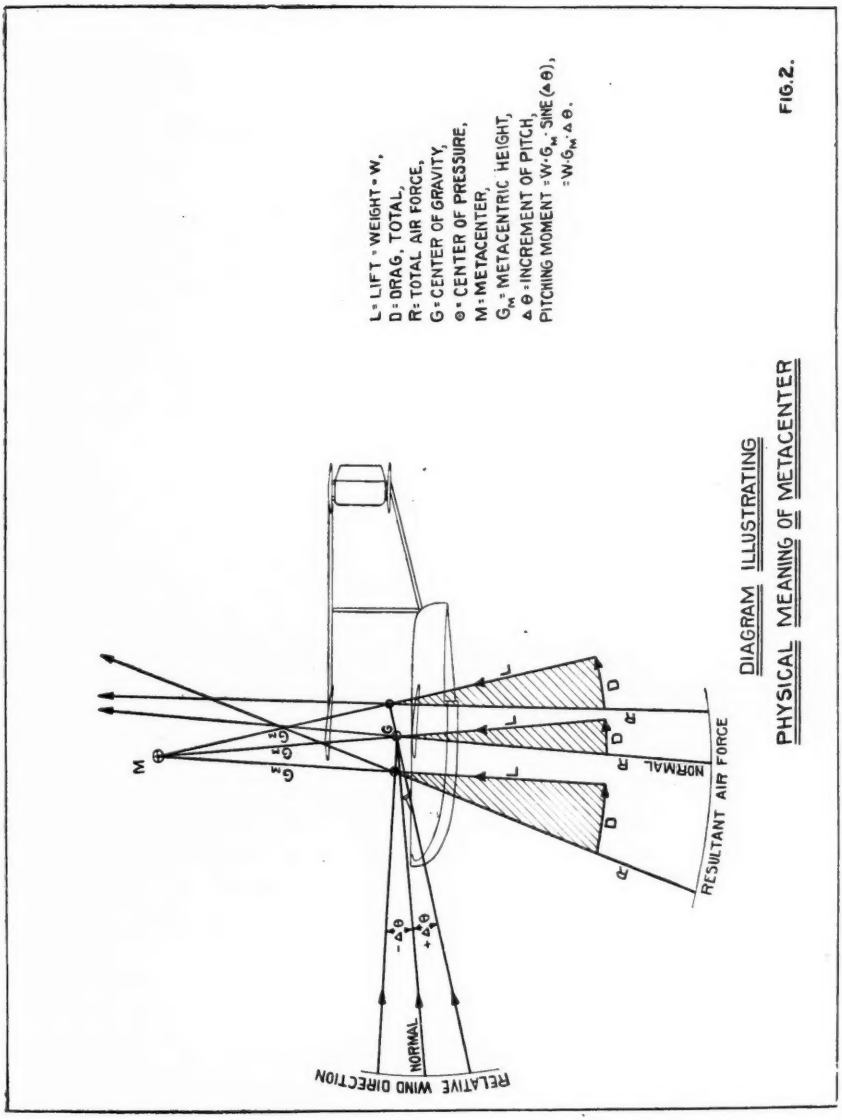
G_M = METACENTRIC HEIGHT

RIGHTING MOMENT = $WG_M \sin \Delta\theta$

$= W \cdot G_M \cdot \Delta\theta$

FIG. 1.

APPENDIX II.


L = LIFT = WEIGHT = W,
D = DRAG, TOTAL,
R = TOTAL AIR FORCE,
G = CENTER OF GRAVITY,
Θ = CENTER OF PRESSURE,
M = METACENTER,
G_M = METACENTRIC HEIGHT,
Δθ = INCREMENT OF PITCH,
PITCHING MOMENT = W·G_M·SINE(Δθ),
= W·G_M·Δθ.
DIAGRAM ILLUSTRATING
PHYSICAL MEANING OF METACENTER
FIG.2.
RESULTANT AIR FORCE
NORMAL
RELATIVE WIND DIRECTION
NORMAL
M
G
L
D
R
$-\Delta\theta$
$+\Delta\theta$

APPENDIX II.

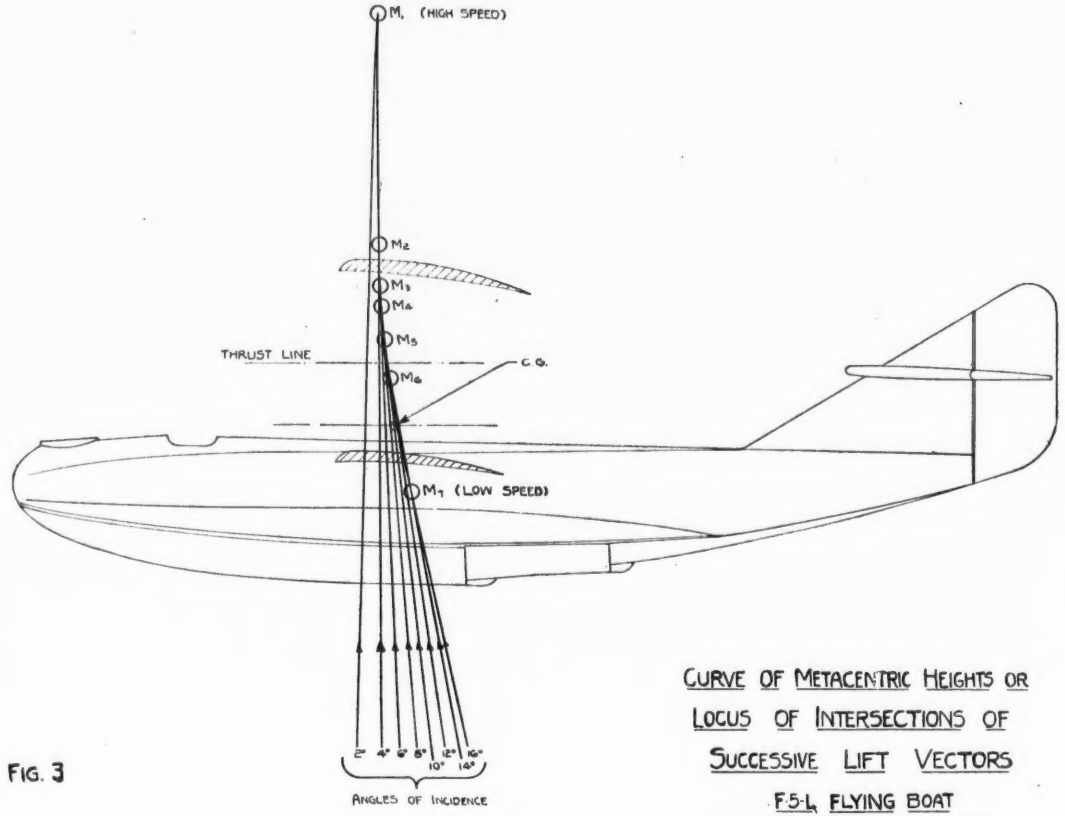


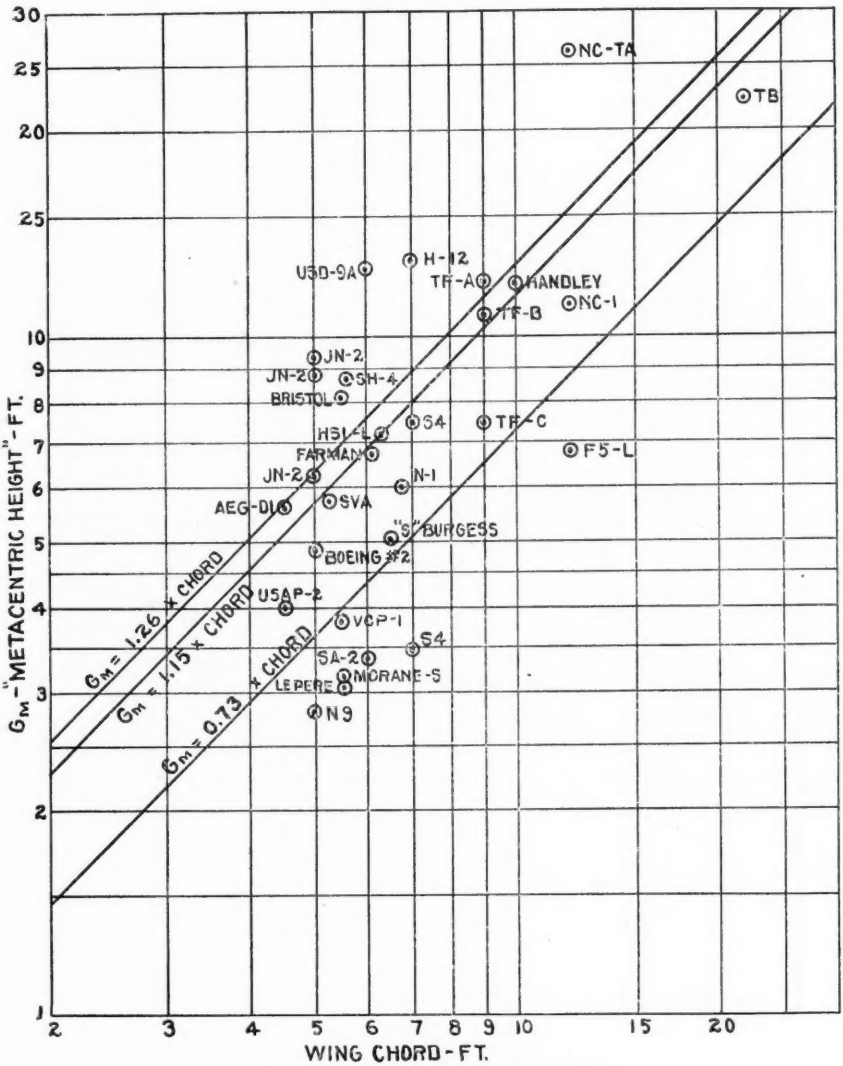
FIG. 3

CURVE OF METACENTRIC HEIGHTS OR LOCUS OF INTERSECTIONS OF SUCCESSIVE LIFT VECTORS

F.5-L FLYING BOAT

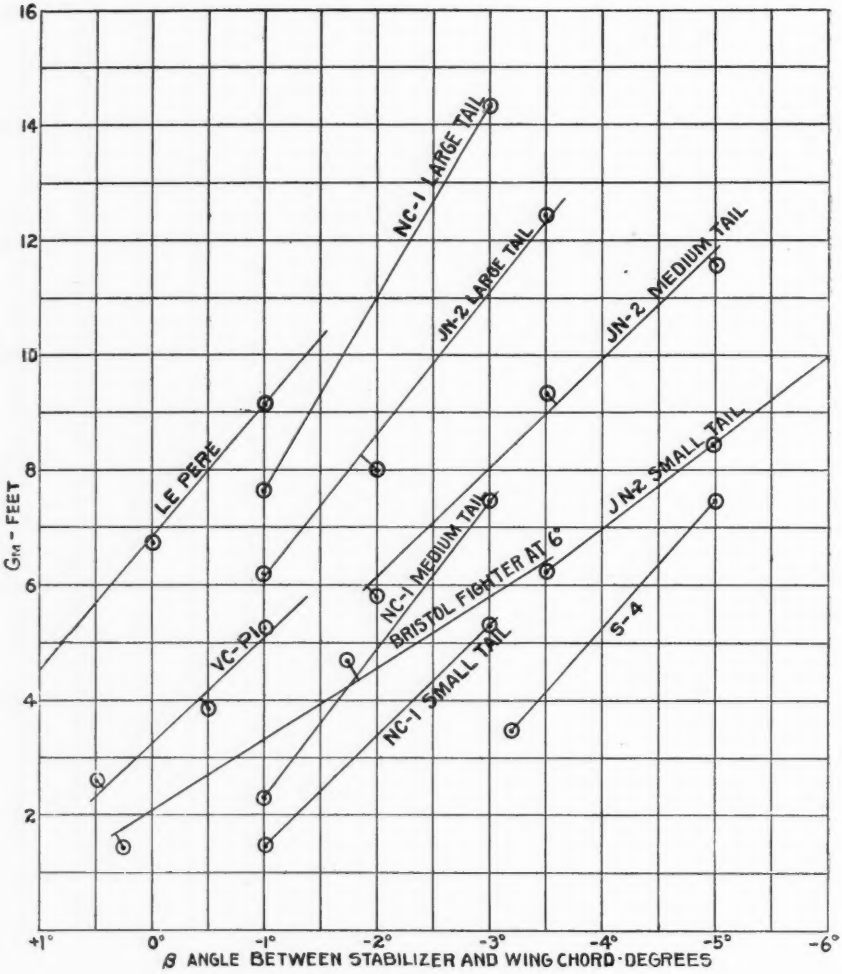
DATA FROM WIND TUNNEL TESTS

APPENDIX II.



METACENTRIC HEIGHT
AT NORMAL FLYING ATTITUDE FIG. 4.

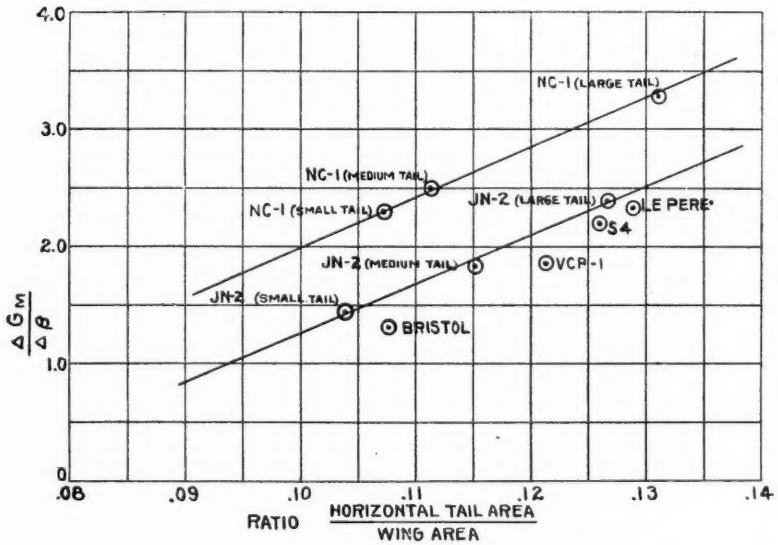
APPENDIX II.



METACENTRIC HEIGHT
EFFECT OF CHANGE IN ANGLE OF
STABILIZER SETTING

FIG. 5.

APPENDIX II.

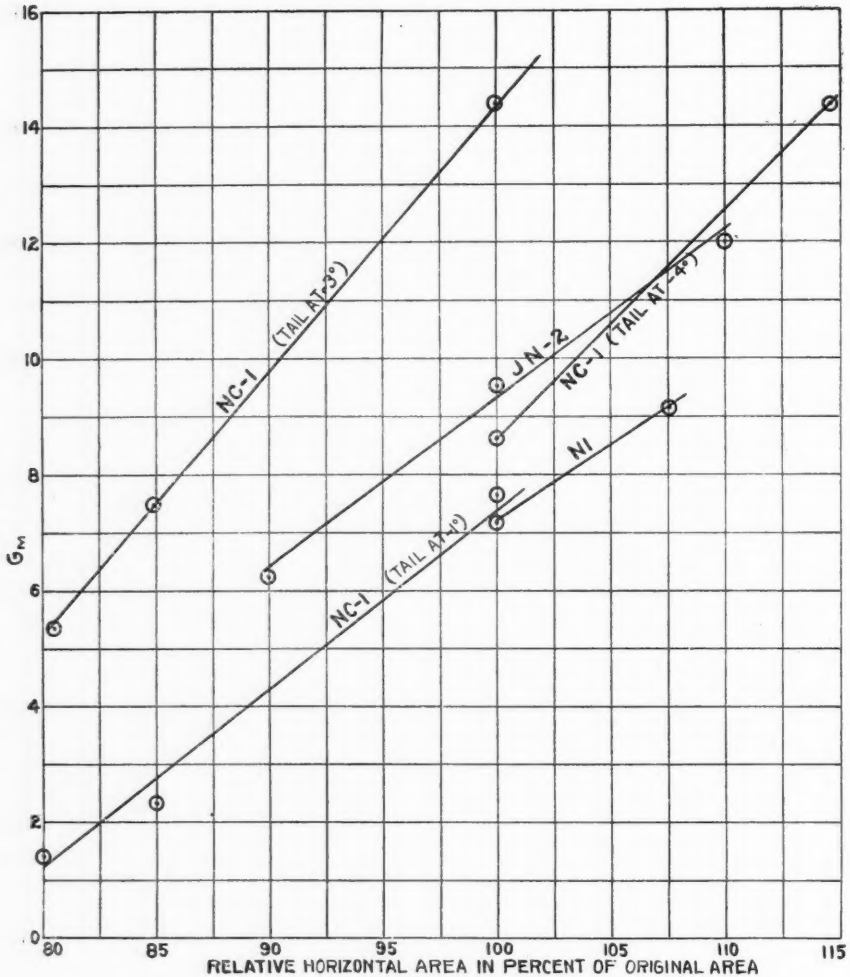


METACENTRIC HEIGHT

DEPENDENCE OF THE EFFECT OF CHANGE IN ANGLE OF STABILIZER SETTING UPON THE AREA OF HORIZONTAL TAIL SURFACES

FIG. 6.

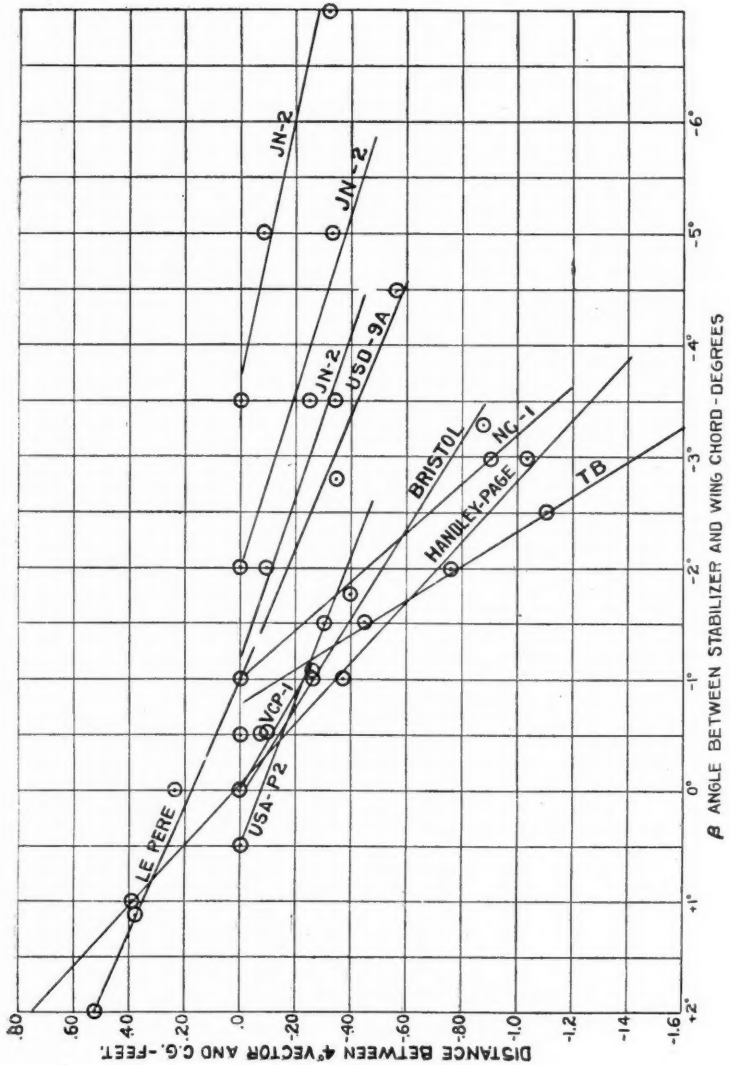
Appendix II.



METACENTRIC HEIGHT
EFFECT OF CHANGE IN AREA OF HORIZONTAL TAIL SURFACE

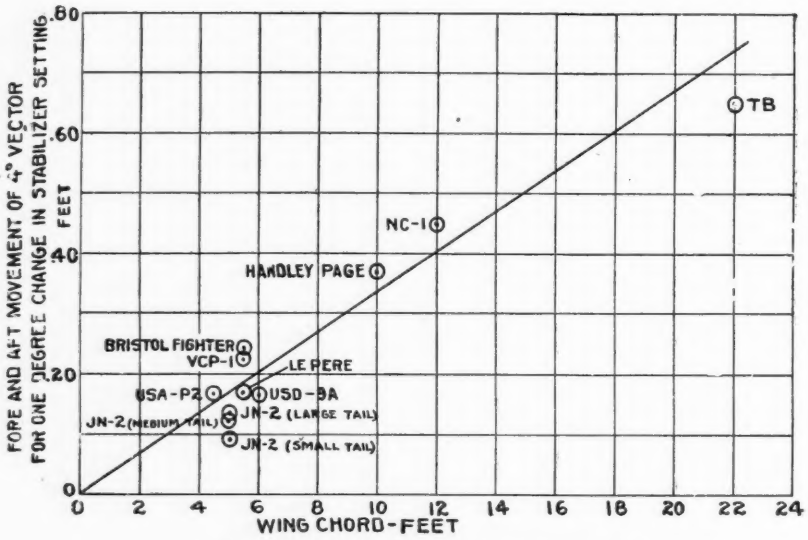
FIG. 7.

APPENDIX II.



EFFECT OF ANGLE OF STABILIZER SETTING
OF FORE AND AFT LOCATION OF 4° VECTOR
(CHANGE OF BALANCE)

FIG. 8.



RELATION BETWEEN WING CHORD AND FORE AND AFT MOVEMENT OF 4° VECTOR FOR 1° CHANGE IN STABILIZER SETTING FIG. 9.
(CHANGE OF BALANCE)

APPENDIX II.

APPENDIX III.*

CONTROL SURFACES.

Part I., Determination of Areas.

Ships' rudders are made large or small depending on the manœuvrability required. For ordinary merchant vessels, a rudder area of the order of only 1/75th the projected side area of the immersed portion of the hull or *carene* may be quite satisfactory. For warships and yachts rapid turning is very important and rudders are made larger; from 1/35th to 1/45th the area of the longitudinal section. The exact size of rudder to use for any design of vessel is determined from an analysis of the rudder areas used on other vessels of similar type with, of course, due consideration given to the amount of dead wood and the shape and location of the rudder. The turning of ships has been studied both by application of the dynamical equations of motion and by careful experiment on actual vessels. Although a considerable literature has been built up dealing with the theory of turning, the naval architect for a new design still depends on experience. But this experience has been carefully analysed in the light of existing theory and made available for immediate application in the form of empirical rules and coefficients.

In a similar manner, the manœuvrability of airships and aeroplanes has been investigated experimentally by full scale and model tests, and by analysis based on theoretical mechanics. The results give a theory of a qualitative nature which may be useful as a guide, but the designer must in the end risk his reputation on his judgment and experience. He cannot predict with confidence the proper sizes to give the rudders, elevators and ailerons of a new design from purely theoretical considerations.

To make the application of experience in new work more direct, I have attempted here to apply the naval architect's method to data assembled for a large number of successful aircraft and to establish empirical rules and coefficients for the design of the control surfaces. To make this possible, the various machines under review are grouped by types into classes and, naturally, the coefficients found apply only to machines of these general types with control surfaces of the same general shapes and location. The various types of aeroplanes and seaplanes are arranged in seven classes, and I will consider these first. A table for airships is given last.

My own experience indicates that, for a normal type of machine, the judicious application of these coefficients will ensure a normal degree of manœuvrability. Machines with radical innovations must be considered apart. For example, ailerons trailing from the rear margin of a wing should be about 11 per cent. of the wing area for flying boats of usual type, but the Curtiss F. boat with interplane ailerons required ailerons of area equal to nearly 18 per cent. of the wing area to give reasonable lateral control.

The aeroplane control surfaces under consideration are the horizontal stabiliser combined with the elevator, the vertical fin combined with the rudder, and the ailerons. No attempt has been made to separate the elevator from the stabiliser or the fin from the rudder; the gross areas only of the combinations are listed.

Horizontal Tail Surface.

The necessary horizontal tail surface should depend on the pitching radius of gyration and the degree of manœuvrability which are roughly fixed by the

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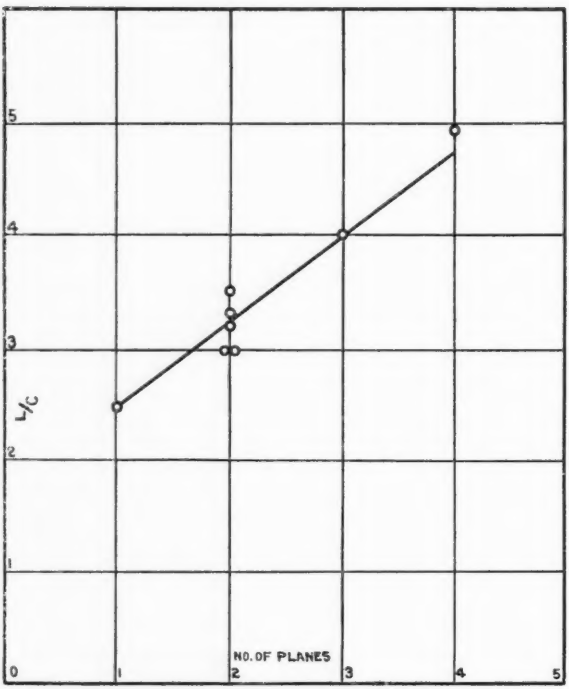
* I am indebted to my assistant, R. B. Beisel, B.S., for help in the preparation of this Appendix.

VARIATION OF $^{L}/_{C}$ WITH NUMBER OF PLANES



L = DISTANCE FROM TAIL HINGE TO C.G. OF AEROPLANE
C = MEAN WING CHORD.

FIGURE I.

APPENDIX III.

procedure of classification by types. Also, the centre of pressure motion between high and low speed attitudes (depth of chord) and the length of the tail must be important variables. These are also fixed in classification by types, at least relatively. Finally, the area of horizontal tail surface should depend on the weight of the machine or on the wing area.

The ratio of length of tail (distance from C.G. to rudder post) to chord length varies from 2.5 for monoplanes to 4.0 for triplanes, and the corresponding average tail surface areas in per cent. of wing area vary from 15 per cent. to 9 per cent. Both theory and the practice of successful designers indicate that the horizontal tail surface depends on chord length and wing area. The triplane with narrow chord has the advantage of requiring a small tail surface.

Table I., which is based on Tables III. to IX. inclusive, gives the length of tail as (t) chord lengths and the horizontal tail surface as (h) per cent. of wing area. The product (th) is there shown to be nearly constant, indicating the reasonable conclusion that long tails may safely be made smaller than short tails. The flying boat class, it will be seen, has an average (th)=41.4, which is appreciably larger than for any other class. This is no doubt due to the projection of the hull forward of the centre of gravity. The twin-engined bombers also have a considerable portion of the fuselage forward of the c.g. and are seen to require a larger value of (th) than the other machines.

Vertical Tail Surface.

The vertical tail surface (v) multiplied by the length of tail (t) in the same notation gives a similar coefficient (tv) which is larger for the flying boats, as would be expected. The large value of (tv) for the monoplanes is not easily explained, but due to the relatively small number of machines listed and the lack of experience with this type, I am inclined to attribute this to the designer's desire to keep on the safe side with a novel type.

Ailerons.

The aileron area is practically a constant fraction of the wing area except that small machines which require a great degree of manœuvrability have slightly larger ailerons. Apparently the span has very little effect on the required aileron area. The reason for this may be that the machines of high aspect ratio, the bombers and flying boats, are not required to manœuvre rapidly. The average aspect ratios are given on Table I. as a matter of interest.

Experiments, both wind tunnel and full scale, indicate that although a long narrow aileron is not quite as effective in producing roll for the same angle of throw, nevertheless the moment about the hinge, which is a measure of the pilot's effort, is considerably less, and for this reason with the same percentage of wing area long narrow ailerons are more efficient than short deep ones. By using especially long narrow ailerons the percentage aileron area given in the tables might be somewhat reduced. Table II. gives aileron data for several German machines, which are included in preparing the averages of Table I. It will be noted that the average aileron area for these machines is much less than the averages given in Table I. It seems to be fairly well agreed, however, that German planes are for the most part very sluggish on lateral control.

Fig. 1 shows the relation between the length of tail in terms of the mean wing chord and the number of planes for the several classes of machines.

Table X. summarises data regarding fin and control surface areas for a number of rigid and non-rigid airships. It will be noted that the coefficients deduced are not so nearly constant as they are for aeroplanes, but it is also known that airships differ very widely in their controllability.

TABLE I.

(SUMMARY OF TABLES III.-IX.)

AVERAGE CONTROL SURFACE COEFFICIENTS.

No. in Class.	Class.	Horizontal tail surfaces in per cent. wing area. (h)	Vertical tail surfaces in per cent. wing area. (v)	Aileron surface in per cent. wing area (a)	Distance from tail hinge to c.g. of elevator plane in terms of mean wing chord (t)	(th)	(tv)	Aspect ratio (maximum span over maximum chord).
8	Monoplanes	14.8	6.1	12.5	2.5	37.0	15.2	5.0
20	Single-Seater	11.8	4.4	12.9	3.0	36.4	13.2	5.9
17	Two-Seater Non-Training	11.7	4.3	12.6	3.2	37.4	13.8	7.3
4	Seaplanes (Two-Seater)	11.4	4.0	11.3	3.3	37.6	13.2	8.7
7	Triplanes	9.2	3.7	11.2	4.0	36.8	14.8	9.6
12	Twin-engined Bombers (Biplanes)	11.1	4.2	11.3	3.5	38.8	14.7	9.2
11	Flying Boats	13.8	6.3	11.2	3.0	41.4	18.9	10.4

TABLE II.

AILERON CONSTANTS FOR GERMAN MACHINES.

Name.	Aileron Surface in % Wing Area. (a)
Friedrichshafen	8.0
Gotha	11.4
A.E.G.	5.4
A.E.G. Armoured	11.8
Pfalz Single-Seater	8.9
Pfalz DX II.	7.5
Albatross D-5	7.9
Fokker D-7	5.2
Fokker E-5	7.9
Rumpler C-4...	9.6
Hannoveraner	9.1
L.V.G.—CV	6.3
Rumpler G 117	8.4
Roland D-2	6.7
D.F.W.—C-5	6.3
Average	8.0

TABLE III.

MONOPLANES.

Designation.	Area Wings.	(h)	(v)	(t)	(a)	Aspect Ratio.
Loening (M-8-o)	251	15.0	6.7	2.9	11.6	4.4
Loening (M-8)	224	15.2	8.0	3.0	16.8	4.8
Gourdou 2-Cl	202	13.8	5.0	2.3	11.7	4.8
Morane Parasol A.R. ...	194	10.0	4.6	2.7	11.7	5.9
Gourdou C-1	177	6.9	7.6	2.3	11.3	4.8
Junker All Metal	158	19.1	5.1	2.5	12.9	4.9
Morane Parasol 27... ...	145	14.3	5.4	2.2	11.6	5.3
Bristol Monoplane	140	24.1	6.6	2.4	12.4	5.2
Average	—	14.8	6.1	2.5	12.5	5.0

TABLE IV.

SINGLE-SEATERS.

Designation.	Area Wings.	(h)	(v)	(t)	(a)	Aspect Ratio.
Parnall Panther	336	11.2	3.3	2.7	13.4	4.7
Spad 20-Cl	312	11.2	3.2	3.1	11.9	5.9
Nieuport 29-Cl	288	12.3	4.3	—	11.1	6.5
Sopwith Salamander ...	272	9.5	4.3	2.5	18.7	6.2
Sopwith Snipe	271	9.6	4.4	2.5	16.6	6.2
Sopwith Dolphin	263	11.6	4.4	3.3	14.4	7.2
Salmson 3-Cl	257	12.5	6.6	3.2	13.0	7.3
Vickers Cl	257	9.0	4.6	3.0	13.0	5.9
Sopwith Pup	254	13.7	3.2	2.6	8.6	5.2
Spad 21-Cl	253	12.0	4.4	—	11.6	5.6
Pfalz D-3	240	10.4	3.7	2.9	8.9	5.7
S.E.-5	240	12.5	5.4	2.5	13.3	5.4
Sopwith Camel	240	10.2	3.3	3.0	15.0	6.2
S.V.A. 5-C	232	10.4	5.6	3.5	11.7	5.0
Fokker D-7	219	16.5	4.0	3.3	5.2	5.6
Spad 13-Cl	215	14.2	5.2	2.9	10.0	5.2
De H.-5	212	12.0	4.0	3.1	21.8	5.7
B.A.T. Bantam	185	12.1	3.7	2.9	9.7	6.4
Nieuport 28-Cl	181	12.1	5.0	3.3	10.9	6.3
Morane Saulnier C-1 ...	164	12.2	4.8	—	12.0	6.0
Average	—	11.8	4.4	3.0	12.9	5.9

TABLE V.

TWO-SEATERS (NON-TRAINING).

Designation.	Area Wings.	(h)	(v)	(t)	(a)	Aspect Ratio.
Breguet 16 Br. 2	783	8.4	4.0	2.9	13.0	7.0
Salmson 4 Ab-2	675	10.4	4.8	3.0	12.8	7.6
Pomilio VL-12	580	10.3	3.5	3.6	8.0	8.1
Breguet 14-A 2	527	10.2	4.6	2.9	12.1	7.2
De H.-4	514	14.2	4.4	3.5	16.0	7.8
U.S.D.-9a	514	11.5	4.3	3.5	14.8	7.9
Vickers F-B-14	427	12.4	4.9	2.9	13.0	6.3
Bristol Fighter F-2 B ...	406	12.0	4.1	3.1	12.8	7.1
Bristol Fighter U.S. ...	403	10.8	4.1	3.1	14.0	7.1
S.E.A. 4C-2	395	10.0	4.5	3.2	11.1	7.1
Le Pere C-11	391	12.8	4.2	2.9	14.3	7.1
Hannoveraner	360	14.2	3.6	3.2	9.1	7.7
Rumpler C-4	360	10.8	3.0	4.1	9.6	8.4
A.E.G. Armoured Biplane	358	9.8	3.8	2.8	11.8	8.0
Avro 530	346	15.0	3.8	3.3	16.7	6.6
Spad 11-A2	314	13.4	6.8	4.0	8.3	7.9
Hanriot Dupont 3-C2 ...	274	12.9	4.3	3.2	16.4	6.0
Average	—	11.7	4.3	3.2	12.6	7.3

TABLE VI.

SEAPLANES—TWO-SEATERS.

Designation.	Area Wings.	(h)	(v)	(t)	(a)	Aspect Ratio.
Curtiss R-6	613	11.0	3.8	2.9	8.8	9.1
Curtiss N-9	496	10.1	4.0	3.7	11.0	10.7
Aeromarine 39-B	494	11.3	3.8	2.6	11.7	7.5
Avro 504-L	330	13.2	4.5	3.8	13.7	7.5
Average	—	11.4	4.0	3.3	11.3	8.7

TABLE VII.

TRIPLANES.

Designation.	Area Wings.	(h)	(v)	(t)	(a)	Aspect Ratio.
Caproni CA-4	2223	8.6	3.6	4.3	10.2	13.8
Bristol-Braemer	1905	9.5	2.8	3.6	10.0	9.6
Nieuport T.T.	1100	9.5	3.7	3.7	10.9	9.1
Le Pere Triplane	870	9.1	4.3	4.2	12.7	9.6
Avro 547	498	8.8	3.3	3.9	13.8	7.8
Kirkham Triplane	309	8.8	4.5	4.5	6.3	9.1
Sopwith Triplane	231	10.2	3.0	3.9	14.7	8.0
Average	—	9.2	3.7	4.0	11.2	9.6

TABLE VIII.

TWIN-ENGINED BOMBERS (BIPLANES).

Designation.	Area Wings.	(h)	(v)	(t)	(a)	Aspect Ratio.
Handley Page V-1500 ...	2898	12.4	4.4	3.3	12.0	10.1
Caproni C-5	1420	9.4	4.4	2.7	10.4	8.4
Vickers Vimy F.B.-27 ...	1320	13.0	3.6	3.8	18.1	6.4
Handley Page 0.400 ...	1317	10.4	3.7	4.4	10.0	10.0
Farman C-23	1076	11.2	3.7	4.0	9.6	9.4
Martin Bomber	1070	10.0	5.0	3.9	12.1	10.8
Farman 50-Br. 2	1026	9.1	4.1	3.3	8.7	9.7
Avro Bomber 529-A ...	922	9.2	3.7	3.4	13.9	8.7
De H.-10	833	15.3	4.1	3.4	13.0	8.9
Boulton and Paul P-8 ...	770	12.5	4.5	3.1	14.0	8.1
Friedrichschafen G-2 ...	753	11.6	4.2	3.6	8.0	10.4
A.E.G. Bomber G-4 ...	730	9.4	4.8	3.0	5.4	9.0
Average	—	11.1	4.2	3.5	11.3	9.2

TABLE IX.

FLYING BOATS.

Designation.	Area Wings	(h)	(v)	(t)	(a)	Aspect Ratio.
NC-1	2380	21.4	6.2	3.4	11.1	10.5
F-5-L	1397	12.6	6.3	3.2	8.5	13.0
P-5	1296	15.5	4.5	3.2	6.6	9.5
Curtiss H-16	1164	12.4	5.1	3.5	11.2	13.4
Curtiss H-12	1108	12.3	7.7	3.4	10.4	13.0
Curtiss HS-2	803	12.6	5.7	3.1	13.0	11.8
Macchi M-12	656	*7.8	6.7	2.6	9.7	7.2
Aeromarine 40	504	12.9	6.7	2.1	11.5	7.2
Macchi 9 Bis	480	9.1	5.3	3.1	18.4	8.7
Curtiss M-F	401	15.7	8.7	3.0	11.2	10.9
Curtiss F	387	13.9	6.5	2.7	†17.8	8.7
Average	—	13.8	6.3	3.0	11.2	10.4

* Omitted in average owing to large sweepback.

† Omitted in average owing to interplane ailerons.

TABLE X

TYPE	AIRSHIP CLASS OR DESIGNATION	VOLUME CUBIC FEET (V)	LENGTH OVERALL FEET (L)	MAXIMUM DIAMETER (D)	MAX. CROSS SECT. AREA (A_x)	AREAS CONTROL SURFACES SQ. FT. FIN	RUDDER (A_R)	FIN + RUDDER (A_v)	STABILIZER	ELEVATOR (A_E)	STAB. + ELEVATOR (A_H)	A_v/A_x	A_H/A_x	A_R/A_v	A_E/A_H	COEFFICIENTS. $K_v = \frac{A_v L}{V}$	$K_H = \frac{A_H L}{V}$
NON-RIGID	S.S. ZERO	70,000	143	30.0	707	187	43	230	220	64	284	.33	.40	.19	.23	.47	.58
	B-(U.S)	84,000	160	31.5	780	292	64	356	328	128	456	.46	.58	.18	.28	.68	.87
	E- "	95,000	162	33.5	882	207	83	290	216	166	382	.33	.43	.29	.43	.50	.65
	O-(ITALIAN)	127,000	177	IRREG.	1076	322	172	494	10	253	263	.46	.24	.35	.96	.69	.37
	P- "	176,000	203	"	1,450	384	214	598	—	617	617	.41	.43	.36	1.00	.69	.71
	C-(U.S)	182,000	192	41.75	1,370	342	82	424	420	118	538	.31	.39	.19	.22	.45	.57
	D- "	186,000	198	41.75	1,370	454	98	552	506	196	702	.40	.51	.18	.28	.59	.75
	C STAR	210,000	217	TRI-LOBE	1,395	287	67	354	574	134	708	.25	.51	.19	.19	.37	.73
	CHALAIS MENDON C-M-S	320,000	262	45.7	1,640	581	237	818	474	194	668	.50	.41	.29	.29	.67	.55
	ZODIAC(U.S)	328,000	262	50.3	1,990	633	248	881	585	253	838	.44	.42	.28	.30	.70	.67
	ASTRA	340,000	262	TRI-LOBE	1,970	646	216	862	970	323	1,293	.44	.66	.25	.25	.66	1.00
	NORTH SEA	360,000	262	" "	2070	620	122	742	880	244	1,124	.36	.54	.16	.22	.54	.82
	M (ITALIAN)	440,000	269	IRREG	2,460	775	345	1,120	—	647	647	.46	.26	.31	1.00	.69	.40
RIGID	R-9	889,310	526	53.0	2,206	1,100	576	1,676	2,140	480	2,620	.76	1.19	.34	.18	.99	1.55
	R-23	997,500	535	53.0	2,206	1,400	480	1,880	1,800	480	2,280	.85	1.04	.26	.21	1.01	1.22
	R-29	1,000,000	539	53.0	2,206	1,280	427	1,708	1266	422	1,688	.77	.77	.25	.25	.92	.91
	R-31	1,560,000	615	65.6	3,380	1,602	458	2060	1,707	484	2,191	.61	.65	.22	.22	.81	.86
	L-33	2,013,000	643	78.8	4,877	1,405	471	1,876	1,925	580	2505	.38	.51	.25	.23	.60	.80
	L-49	2,013,000	643	78.8	4,877	1,400	464	1,864	1,896	560	2,456	.38	.50	.25	.23	.60	.79
	R-38 *	2,880,000	695	85.5	5,740	1,950	667	2,617	2,204	734	2,938	.45	.51	.25	.25	.63	.71

* EXTERNALLY BALANCED SURFACES, INTERNALLY BRACED

APPENDIX III.

CONTROL SURFACES.

Part 2, Determination of Shape.

In order to increase manœuvrability without imposing an undue strain on the pilot, balanced control surfaces are being used on various machines, especially the large bombers and flying boats. The use of balanced controls was forced by necessity on large aeroplanes when data for their design was lacking. Naturally experience is still incomplete, but I venture to say one could now easily compile a fat handbook on how not to do it. I know of no detail of aeroplane design where so many good designers have gone astray. Of course, a very slight amount of balance is a timid solution which causes no trouble, but attempts at nearly complete balance require courage.

Naval Architects have been balancing rudders on vessels for a long time and presumably must have learned a good deal about it, but it is curious to note how little the aeronautical engineer has profited. The aeronautical people apparently have insisted on making the same old mistakes and learning at first hand.

To illustrate this:—Naval Architects hinge a rudder to the rear of the deadwood with the balancing portion underhung below in the clean water flow. Forward of this underhung balancing portion the deadwood is cut away liberally. Where spade rudders are used there is no adjacent deadwood. This practice has resulted from experience which indicates poor turning qualities if the rudder is so placed as to create back pressures on the deadwood of a nature to resist turning.

Now consider the rudders on the Zeppelins, on the flying boat F.5, and similar arrangements on many other aircraft. The Naval Architect would never consider designing a ship with such a rig. It is interesting to note that the post-war Zeppelin, the "Bodensee," definitely abandons the old form of balanced rudder for a more reasonable, but still to my mind, imperfect type. They have given the straight trailing rudder an overhang, but have neglected to cut away the fin immediately forward of the overhanging portion. It will be interesting to observe what will be the next change.

Various types of balancing are employed and may be roughly divided into the following classes:—

1. *Free simple balance*, as used on the rudders of the N.C. flying boat and Caproni biplanes and triplanes. See No. 1, Fig. 2.

2. *Dove-tailed balance*, as used on the rudders of Zeppelins and ailerons of many German aeroplanes. See No. 2, Fig. 2.

3. *Faired contour balance*, as used on the Hanriot C.3 and Morane Saulnier C.2 machines. See No. 3, Fig. 2.

4. *Auxiliary balance*, as used on many German seaplanes. See No. 4, Fig. 2.

5. *Overhung balance*, as used on the elevators and ailerons of the N.C. flying boats, the A.E.G. Bomber and Vickers Vimy. See No. 5, Fig. 2.

Regardless of the merits of the various types of balancing, the objects of balancing are as follows:—First, the load on the control cable should be a minimum for all conditions of flight without overbalancing or fluttering; second, the air resistance of the added balancing portion should be a minimum; third, the added weight should be a minimum; and fourth, from the structural point of view, the stresses introduced should be a minimum.

The free simple balanced area (No. 1, Fig. 2), if made of a double cambered aerofoil having a small c.p. movement, can be more nearly balanced for all flight conditions than any of the other types. Owing to the circumstance, however, that it is not preceded by a fixed surface, the area required to give proper control is greater than for a trailing control surface, and the structural difficulty of pro-

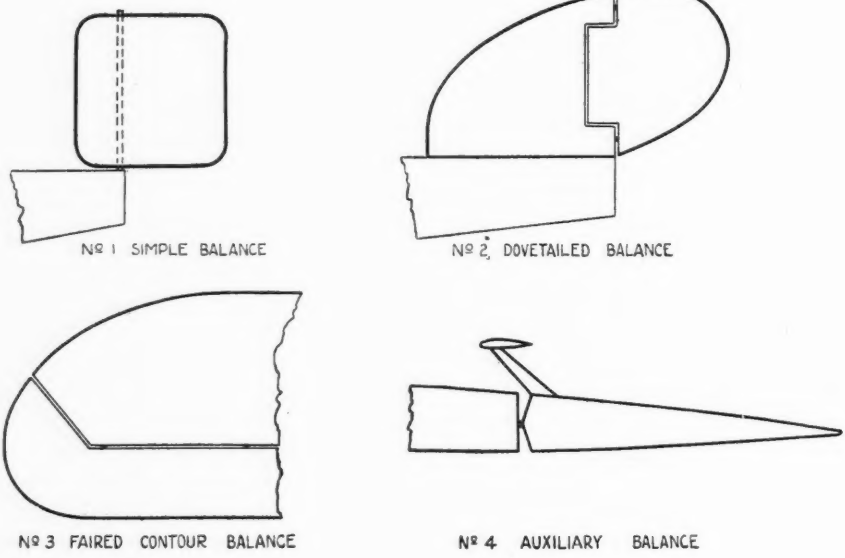


FIGURE 2

APPENDIX III.

viding efficient bracing is apparent. The free simple balance can, however, be used very advantageously for rudders on machines with a biplane tail, as in the N.C. boats. There the centre rudder is free and is used to balance the two outside rudders. This requires "overbalancing" the centre rudder and connecting all three rudders to work in parallel so as to eliminate any tendency of the centre rudder to flutter.

The dove-tailed balance (No. 2, Fig. 2) cannot be recommended as a good type. If the hinge leakage were eliminated and the movement of the controls at high speeds were very small in amount, this type of balancing would no doubt be ideal from the standpoint of low air resistance. A movement of only a few degrees, however, will introduce a marked increase in drag, and at the same time the action of the air flow on the balancing portion is indeterminate, due to the turbulence introduced. At large angles of the control surface, the balancing portion is blanketed by the preceding fixed surface and the effectiveness of the combination is materially reduced due to the increased pressure on the back of the fixed surface. This form of balancing is rejected by Naval Architects, and it is interesting to note that in aeronautics it is becoming more rare.

The faired contour balance (No. 3, Fig. 2) is often used for ailerons in order to preserve a fair form of wing tip which is supposed to confer some aerodynamic advantage. However, such ailerons are quite indeterminate so far as calculation of balance is concerned due to the uncertainty of the angle of attack of the air striking the balancing portion. At large angle of incidence of the main wings, the air spilling under the wing tips produces abnormally high pressures on the balancing portion of the aileron and may cause overbalance and fluttering.

The auxiliary balance (No. 4, Fig. 2) has to date been used on only a few machines outside of Germany and its advantages are not well known. The area required should be small, and torsion in the control surface spar due to a balancing portion is eliminated.

The overhung balance (No. 5, Fig. 2), which is perhaps more widely used than any other type, seems to be the most desirable of the types which use a balancing area forming part of the control surface. The extension or balancing portion is working in comparatively free air and should, therefore, at all times be unblanketed and free from mutual reactions with the fixed surfaces. It is possible to use a double cambered surface for the extension which will operate equally well for positive or negative angles of the control surface.

Calculation of Balance.

The calculation of the required amount of balancing area for control surfaces must be an approximation. If it were possible to obtain separately the lift, drag and the centre of pressure coefficients for the balancing portion and the trailing portion for all conditions of flight, the required amount of balance might be calculated. However, owing to the variation in the profile used on the balancing area and on the trailing portion and to the unknown air flow around a wing tip, an elaborate calculation is not justified. The most desirable method for design is to employ a simple straightforward calculation which uses only the most important variables and then to compare the result with actual practice.

Such compromise with a solution is common in Naval Architecture and yields good results if coefficients are obtained only from successful machines. For the calculation of the coefficients of Table XI., only surfaces of the overhung type are used. First the moment of the trailing portion of the surface about its hinge is calculated as the sum of the moments of fore and aft increments of area, on each of which the centre of pressure is assumed to be at 0.3 chord length[1] from the hinge. The moment of area so obtained is a "righting moment" which it is desired to balance by the "balancing moment" of the overhanging portion of

(1) "Stabiliser and Elevator Pressure Distribution," Bulletin of the Experimental Department, Airplane Engineering Division, U.S.A., Vol. II., No. 3, December, 1918.

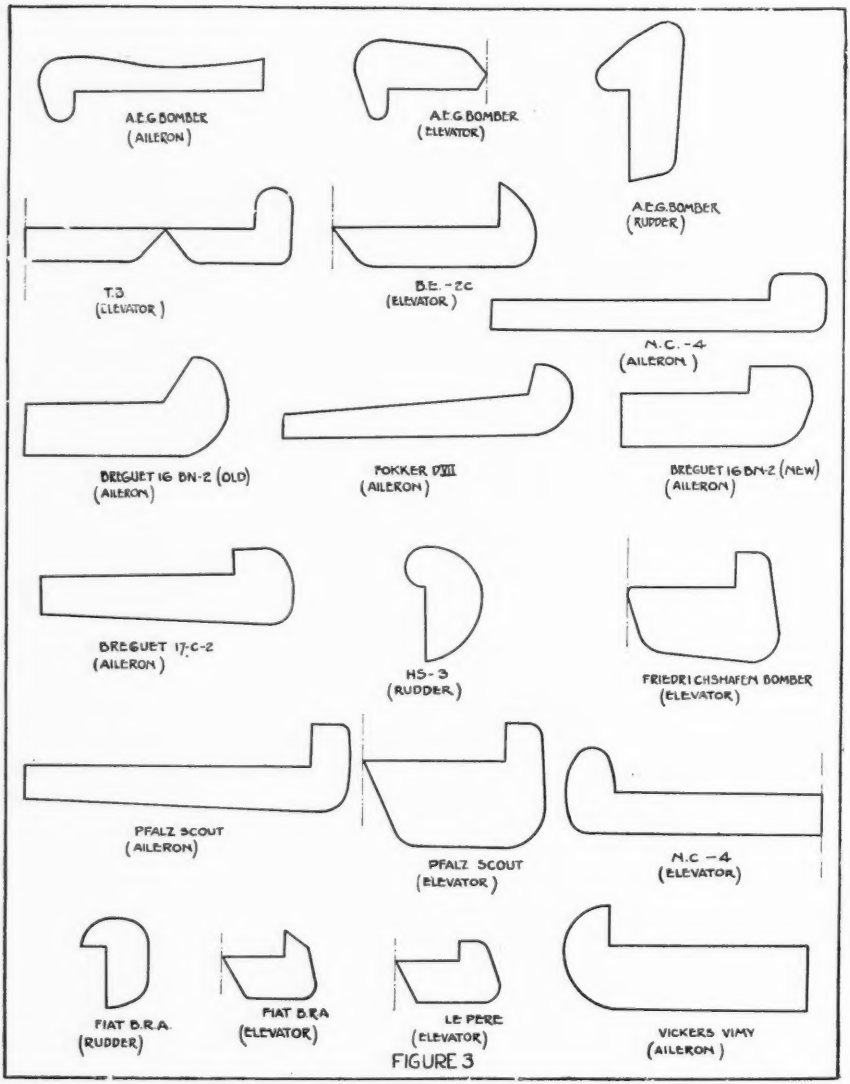


FIGURE 3

APPENDIX III.

the control surface computed by graphical integration in a similar manner, except that the centre of pressure is taken at 0.2 chord length[2] from leading edge. The unit pressures on the two portions of the control surface are assumed equal. The ratio of the moment about the hinges of the balancing portion, "balancing moment," to the moment of the trailing portion tending to return the rudder to neutral, "righting moment" is a coefficient of the order of 0.4 to 0.6 for control surfaces with overhung balance. The results of calculation on several machines are given on Table XI., the shapes of the various surfaces being shown on Fig. 3.

This data would indicate that the maximum balancing moment should never be more than 65 per cent. of the righting moment. On rudders and elevators where blanketing by the fuselage will tend to reduce the effective lift of the inboard portion of the control surface, this value should be somewhat less or about 50 per cent. These figures are for large machines requiring a maximum amount of balancing. For small machines correspondingly smaller values can be used. No account is here taken of the case of control surfaces which lie partially in the propeller slip stream or in an abnormal position with respect to "down wash" from the wings.

The calculation of the simple free balance type of rudder is more simple. The centre of pressure is taken at 0.2 chord length from leading edges and care taken that the axis of rotation does not lie aft of this point.

The auxiliary balance type is a little more indefinite, and I am not prepared to suggest a calculation without more data or at least some knowledge of the velocity of the air flowing over the top of a wing in the region of the auxiliary surface. For large angles of incidence of the wings this velocity appears to be entirely indeterminate.

TABLE XI.

Machine.	Control.	$\frac{\text{Balancing Moment.}}{\text{Righting Moment.}}$	
A.E.G. Bomber	Aileron	.50	
A.E.G. Bomber	Elevator	.43	
A.E.G. Bomber	Rudder	.40	
T.B.	Elevator	1.00	Wind tunnel tests show indication of instability.
B.E.-2C	Elevator	.64	Wind tunnel tests show proper degree of balance.
N.C.-4	Ailerons	.58	
Breguet 16 BN-2 (Old) ...	Ailerons	.83	Wind tunnel tests by Eiffel (Resumé 1919) show degree of balancing in order shown.
Fokker D-VII.	Ailerons	.45	
Breguet 16 BN-2 (New)...	Ailerons	.37	
Breguet 17-C-2	Ailerons	.22	
HS-3	Rudder	.47	
Friedrichschafen Bomber	Elevator	.40	
Pfalz Scout	Ailerons	.65	
Pfalz Scout	Elevators	.25	
N.C.	Elevators	.63	
Fiat B-R-A	Rudder	.55	
Fiat B-R-A	Elevator	.36	
Le Pere	Elevator	.26	
Vickers Vimy	Aileron	.20	

(2) "Airplane Control Surfaces," J. C. Hunsaker and T. H. Huff, "Aviation," Vol. I., No. 5, October 1, 1916.

APPENDIX IV.

Normand's Weight Equation (Rigid Airships).

J. A. Normand[1] developed approximate formulæ for estimating the characteristics of vessels based upon a weight equation expressing the total weight of the ship as the sum of the principal weight groups, each given in terms of the independent variables involved in the design. By the use of this equation a rapid estimate can be made of the effect of a change in any of the variables on the ship as a whole, and of the effect on each group. The method is fairly common among naval architects. For example, the change in displacement and power required by a change from 12in. to 14in. guns can be calculated roughly. Likewise, it can be shown that the addition of an admiral and his staff to an otherwise well-balanced battleship design calls for 40 tons more displacement with corresponding increases in power and fuel supply.

For rigid airships a similar weight equation can be formed from which the effect of proposed changes can be predicted, as well as a general indication as to where it is most worth while to attempt to save weight.[2]

For this purpose, consider the total weight in the air as made up of the following weight groups :—

A. *Outer cover;* complete with fastening, seams, dope, lacing and local stiffening.

B. *Gas bags;* complete with sleeves, appendages and fastenings, but without valves.

C. *Longitudinal girders;* complete including mains and intermediates, corridor structure, local bow stiffening, mooring attachments, stern piece, but not attachments to transverse members.

D. *Transverse framing;* main and intermediate transverses, together with connection with longitudinals, wire terminals and attachments for car suspension.

E. *Shear wires;* diagonal strength wiring to resist shear between hull girders.

F. *Transverse wires;* wiring of main transverses.

G. *Netting;* mesh wiring and netting to distribute pressure of gas bags to hull framing, also axial wire, if any.

H. *Fins and rudders;* complete in place with covering, hinges and quadrants, but not operating gear in ship.

I. *Hull fittings;* mooring and handling tackle, valves, valve controls, gas exhaust and filling trunks, access ladders and walkways, look-out stations, ventilation, rudder operating mechanism outside control car, reserve ballast.

J. *Machinery;* all machinery weights and power cars including engines, gearing, clutches, propellers, radiators, water and auxiliaries not in the hull of the ship, empty oil and gasoline tanks in cars, and piping in cars.

K. *Fuel;* gasoline and oil necessary for endurance specified, gasoline and oil tanks in hull, piping in hull, special supports for tanks.

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(1) Formules Approximatives de Construction Navale, Paris, 1870.
Etude sur les Torpilleurs (translation), Office of Naval Intelligence, U.S., General Information Series, Washington, 1886.
The Displacement and Dimensions of Ships, Int.Eng. Congress, Glasgow, 1901.

(2) I am indebted to Mr. C. P. Burgess for assistance in applying Normand's equation to airships, and I have also had access to Professor Hovgaard's manuscript for his forthcoming book, "General Design of Warships," Spon, London.

L. *Miscellaneous fixed weights*:—

L1. *Electrical;* all electrical equipment except radio, but including lighting, signal and interior communication sets.

L2. *Crew;* the normal crew necessary to operate the ship with their food, clothing and conveniences.

θ. *Independent weights;* cargo, armament, radio, control car with all gear installed, stores, ballast or passengers, margin.

Considering the weight groups, as above described, for airships of similar general construction, that is, with the same number of gas bags and longitudinals, we may establish approximate relations between the weights and the principal dimensions and performance characteristics taken as independent variables.

The following independent variables are fixed by the desired military characteristics :—

V = maximum trial speed.
v = cruising speed.
t = hours endurance at cruising speed.
θ = independent weights arbitrarily specified to be carried, such as passengers, bombs, or cargo.

In addition, the following independent variables must be assumed by the designer as his estimate of the state of the art :—

a = unit weight of outer cover.
b = unit weight of gas bags.
c = unit consumption of engines at speed v.
e = efficiency of propellers and gears.
f = allowed fibre stress in structural material.
m = unit weight of machinery installation.
r = resistance coefficient.

The dependent variables are :—

L = length of ship.
D = diameter of ship.
W = total weight of ship. (Displacement.)

We desire to form an expression for W in terms of all the variables. The total weight W is the sum of the individual weight groups, or

$$W = W_A + W_B + W_C + \text{etc.} = \Sigma W_Z.$$

This is the weight equation of Normand. Let us consider each member in detail.

A. Outer Cover.

The weight of outer cover complete with seams and lacing is proportional to the unit weight of material and to the area covered. The area is determined by the lines of the ship and the principal dimensions, L and D. The total area of the outer cover is proportional to KLD where K is a coefficient depending on the form of the ship which is nearly constant for ships of good form. The weight of outer cover is, therefore, $KaLD$, or considering K truly constant :—

$$W_A \sim aLD.$$

B. Gas Bags.

The gas bags, assumed of constant number, require an area of fabric for the circumferential portions proportional to the area of outer cover or to LD. In addition the ends require an area proportional to D^2. From an examination

of returned weights from actual ships the two portions of the total area of gas bags are very nearly equal. Then

$$W_{B1} \sim bLD \text{ and } W_{B2} \sim bD^2, \text{ where}$$
$$W_B = W_{B1} + W_{B2}.$$

C. Longitudinal Girders.

The ship is designed normally to be in a "hogging" condition, so that the upper longitudinals are in tension, the lower in compression. Such tension in the upper longitudinals is not important, but these members must be designed as beams to withstand bending due to the pressure of the gas bags transmitted to them by mesh wires and netting.

Let w = load per running foot on any girder.
i = moment of inertia of girder section.
d = depth of girder section.
p = gas pressure at girder.
m = bending moment at centre of girder.
a = sectional area of longitudinal element of girder.

Then :—

$$w \sim pD \sim D^2$$
$$m \sim wL^2 \sim D^2L^2$$
$$f \sim md/i \sim md/a\Sigma d^2 \sim D^2L^2/ad, \text{ or } a \sim D^2L^2/df.$$

Suppose $d \sim D$, preserving geometrical similarity, then

$$a \sim DL^2/f \text{ and, therefore, weight} \sim aL \text{ or}$$
$$W_{C1} \sim DL^3/f.$$

The girders in compression may be taken as the entire lower half of the ship, excluding all of the corridor except two bottom corner girders. Consider the ship as a whole bending as a beam subjected to the loads of buoyancy and weight. Then at any cross section, adopt the following notation :—

M = bending moment on ship as a whole.
P = end compression in one girder.
I = moment of inertia of section of ship.
y = distance from neutral plane of ship to any girder.
A = sectional area of girder.

Since the girders are of such slenderness ratio that failure as long columns (crippling) is unlikely, we have :—

$$f = My/I, \text{ and}$$
$$P = fA = My/\Sigma y^2, \text{ but at any section}$$
$$\text{Shear} \sim LD^2, \; y \sim D, \text{ and}$$
$$M \sim L^2D^2$$

$\therefore A \sim L^2D/f$ and the weight of the girders in compression is given by

$$W_{C2} \sim L^3D/f$$

The corridor is somewhat more difficult to generalise upon as its action, as usually constructed, is uncertain. Certainly, the corridor carries as a beam the concentrated loads of fuel and ballast between transverse frames. End compression may also come into it when the ship bends as a whole, but since the shear wires usually have rather indirect fastening to the corridor, it is difficult to believe that the corridor takes any real proportion of their load. It seems safer to consider the corridor as giving local strength only and subject to local bending. The weight of the longitudinal members of the corridor would then vary as that of the longitudinals W_{C1}. The transverse corridor bracing is proportioned after the longitudinal parts and varies in a similar manner. In this connection it

should be noted that the two corridor members which form part of the bottom of the ship are not considered part of the corridor, but part of W_{C2}. We have then as above:—

$$W_{C3} \sim DL^3/f$$
$$W_C = W_{C1} + W_{C2} + W_{C3} \sim DL^3/f.$$

D. Transverse Framing.

The most severe load on a main transverse frame is due to the tension in the transverse wiring caused by a deflated gas bag or excess pressure in one bag. The mean intensity of effective gas pressure is proportional to D, the area of gas bag supported by one wire to D^2, and the total side load ϕ on that wire to D^3. Let:—

a = sectional area of wire.
E = modulus of elasticity of wire.
T = tension in wire.
P = compression in frame.

Since $T^3 = Ea\phi^2/24$, where T/a and E are constant,(1)

and, $\phi \sim D^3 \sim T \sim P$,

and since $W_{D1} \sim PD/f$,

$$W_{D1} \sim D^4/f.$$

The intermediates, if any are fitted, are put in compression by the shear wires, and in bending by gas pressure. Consider the former as the more important; then the shearing force at any section is proportional to the volume up to that section or to LD^2. The tension in the shear wires is proportional to the shear and the load P thrown into the transverse by these wires is expressed by

$$P \sim LD^2$$
$$W_{D2} \sim PD/f \sim LD^3/f$$
and $W_D = W_{D1} + W_{D2}$.

E. Shear Wires.

The area of shear wires cut by any cross section of the ship should be proportional to the shear or to LD^2. Their weight will then be:—

$$W_E \sim L^2D^2.$$

F. Transverse Wires.

These have been considered with W_{D1}, and we have:—

$$W_F \sim D^4.$$

The unit stress in the material of the wires is assumed constant and does not appear.

G. Netting.

The gas bag netting and mesh wiring support per foot length of ship, a unit gas pressure proportional to D and an area of bag between longitudinals proportional to D, or a load per foot run of ship proportional to D^2. The weight of netting per foot length of ship should then vary as D^3, and the weight of netting for the whole ship

$$W_G \sim LD^3.$$

(1) Proof of this formula seems unnecessary. A somewhat similar form has been shown by Cole, "Aeronautical Journal," March, 1920, and by Campbell, Inst. of Nav. Arch., March 25, 1920. The exact form here used applies to the case of uniform lateral load on a wire initially just taut.

H. Fins and Rudders.

The necessary area of fins and rudders is found from experience to vary as LD for ships of usual form. The unit air pressure on these surfaces varies as V^2, and the weight (for similar structures) is therefore :—

$$W_H \sim (LD)^{3/2} V^2.$$

I. Hull Fittings and Reserve Ballast.

For these weights let us assume, for want of better information, variation with displacement as is done for vessels. Then

$$W_I \sim LD^2.$$

J. Machinery.

To a first approximation the resistance to propulsion is represented by

$$R = rL^{2/3}D^{1/3}V^2,$$

where r is an aerodynamic coefficient dependent on the lines of the ship, and but little changed by small variations in the ratio L/D.(1) The power required is then :—

$$J = RV/e = (r/e)\, L^{2/3}D^{1/3}V^3$$

and the total weight of machinery

$$W_J = mJ = (mr/e)\, L^{2/3}D^{1/3}V^3$$

K. Fuel.

The weight of fuel and oil, including necessary tanks, is directly dependent on the consumption of the engines, the power and endurance (at cruising speed) assumed.

$$W_K = cJt = (ctr/e)\, L^{2/3}D^{1/3}V^3$$

L. Miscellaneous.

Under this head for convenience are grouped weights necessary for the ship as a useful and manageable craft, but not altogether proportional to her size, I include :—

L_1. Electrical apparatus for lighting and signalling.
L_2. Crew and their effects.

The above weights are naturally greater for larger ships, but do not increase so rapidly as the displacement. They are only partially under the control of the designer. It seems reasonable to assume that :—

$$W_L \sim LD.$$

θ. Independent Load.

Finally, we have those weights which may be arbitrarily fixed without reference to any other characteristic of the ship, such as cargo, radio, control car, passengers, bombs, margin, etc.

$$W_\theta \sim (LD)^0 = \theta, \text{ a constant.}$$

It will be noted that many of the weight groups increase more rapidly than the displacement. For these groups great size alone is not an advantage. In

(1) There is some reason to believe that r is increased for L/D below 5.5 and above 8.5. For the usual range of ship forms the change is small and rather uncertain.

general the structural weights increase more rapidly than the displacement and the machinery and fuel weights less rapidly. In practice, it seems that the larger Zeppelins have been built with the structural weights increasing much less rapidly than my analysis would indicate.(1) However, it is difficult to judge, because of the necessity for comparing large modern ships with small ships of an earlier date. The Bodensee, however, appears to indicate that a modern small ship can be given a very excellent performance.

It is nevertheless true that in a large ship the designer has opportunities to use materials to more advantage and is not troubled so much by lack of local stiffness, vibration and deterioration. There are many savings of a minor nature which can be made in a very large ship, which tend to throw these estimates on the safe side.

However, it is important to know where and how substantial savings in weight are most likely to be made and for this purpose Normand's method should prove useful.

Differentiation of the Weight Equation.

Normand's weight equation is simply the sum of the weight groups,

$$W = W_A + W_B + W_C + \text{etc.} = \Sigma W_z,$$

where each term W_z is expressed as a function of the principal elements of the design as developed in the first portion of this note. The typical member of the weight equation is of the form

$$W_z = KL^x D^y \alpha^z \beta^w, \text{ etc.} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where L and D are the length and diameter of the ship, and α, β, etc., are other variables entering with exponents z, w, etc.

Case I., Constant Volume.

In the particular case, where the volume is assumed fixed, we may investigate the effect of changing the fulness of the ship or the ratio L/D, while all other variables remain unchanged. Then, differentiating (1),

$$\Delta W_z / W_z = x\Delta L/L + y\Delta D/D \quad . \quad . \quad . \quad . \quad (1a)$$

But $W = KLD^2$ or gross lift.

And, $\Delta W/W = \Delta L/L + 2\Delta D/D = 0$, for constant volume . (2)

Substituting (2) in (1a),

$$\Delta W = \Sigma \Delta W_z = (\Delta L/L)\,\Sigma W_z\,(x - y/2) \quad . \quad . \quad . \quad (3)$$

We may, therefore, calculate the change in W necessitated by a proposed change in L with corresponding change in D to hold constant volume. This change in W in a ship of given volume and characteristics could be added to or subtracted from the "independent" load carried. It is very useful to know whether a gain can be secured by making a fatter or a leaner ship.

Case II., Constant Form.

The case which is of most frequent application contemplates change of any variable while holding L/D and the form constant while the volume is allowed to vary. The designer wishes an immediate answer as to the necessary alteration in his design to meet a proposed change in the military characteristics, in engines, or in some technical limitation.

(1) A. P. Cole, AËRONAUTICAL JOURNAL, p. 118, March, 1920.

Assuming L/D constant, the expressions for the weight are simplified and become:—

$$W_A \backsimeq aL^2, \qquad W_H \backsimeq L^3V^2,$$
$$W_B \backsimeq bL^2, \qquad W_I \backsimeq L^3,$$
$$W_C \backsimeq L^4/f, \qquad W_J \backsimeq (mr/e)\,L^2V^3,$$
$$W_D \backsimeq L^4/f, \qquad W_K \backsimeq (ctr/e)\,L^2V^3,$$
$$W_E \backsimeq L^4, \qquad W_L \backsimeq L^2,$$
$$W_F \backsimeq L^4, \qquad W_\theta \backsimeq \theta.$$
$$W_G \backsimeq L^4,$$

In all expressions for weight D is now eliminated and the typical member of the weight equation takes the form

$$W_z = KL^x\alpha^z\beta^w, \text{ etc.} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

which by total differentiation gives

$$\Delta W_z/W_z = x\Delta L/L + z\Delta\alpha/\alpha + \text{etc.} \quad . \quad . \quad . \quad (5)$$

But

$$W = KL^3, \text{ and}$$
$$\Delta W/W = 3\,\Delta L/L \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Substituting (6) in (5),

$$\Delta W_z = W_z\,(x\Delta W/3W + z\,\Delta\alpha/\alpha +, \text{ etc.}), \text{ and} \quad . \quad . \quad (7)$$
$$\Delta W = \Sigma\Delta W_z = 1/(1 - \Sigma xW_z/3W)\Sigma W_z\,(z\,\Delta\alpha/\alpha +, \text{ etc.})$$
$$\Delta W = N\Sigma W_z\,(z\,\Delta\alpha/\alpha +, \text{ etc.}) \quad . \quad . \quad . \quad . \quad (8)$$

Where

$$N = 1/(1 - \Sigma xW_z/3W) \quad . \quad . \quad . \quad . \quad . \quad (9)$$

The coefficient N is thus seen to be dependent only upon the exponent of the linear dimension in the weight equation, and is, therefore, a factor of proportionality. For rigid airships, N has a value of the order of 4.5. This means that for 100lbs. added to the ship's weights the displacement should be increased by 450lbs. to preserve the same speed, endurance and other characteristics.

The value of N computed for eight modern battleships varies from 2.25 to 2.42, but there is not enough information yet available regarding the weight statements of rigid airships to state the range of variation of N. It seems clear, however, that added weight in an airship of constant L/D ratio requires nearly twice as much additional displacement as in a battleship, and the advantages inherent in greater size are realised more slowly with an airship than with a battleship.

Examples.

To illustrate the use of the naval architect's method of estimating the effect of proposed changes, let us take as an example the following problem:—

With a design of an airship of the L-49 type as a basis, it is desired to know the effect of the following proposed alterations:—

(*a*) Increase the bomb load by 2,000lbs.
(*b*) Use a stronger outer cover 25 per cent. heavier.
(*c*) Reduce weight of main transverses and longitudinals 15 per cent. by a new type of construction.
(*d*) Increase the speed 5 per cent.
(*e*) Reduce L/D from 8 to about 7.

We must first calculate N for Normand's equation from the weight statement for the type ship chosen.

The principal dimensions and characteristics of the given airship are as follows:—

Type.	L-49.
Length	643ft.
Diameter	78ft. 8in.
Volume	1,940.000 cu. ft.
Gross lift	129,800lbs.
Maximum speed	60 m.p.h.
Cruising speed	45 ,,
Total B.H.P.	1,200.
B.H.P. at cruising speed	600.
Fuel capacity	55,000lbs.

CALCULATION OF N FOR A RIGID AIRSHIP OF THE TYPE OF L-49.

Item.	Symbol.	Weight.	x	$xW_z/3W$.
Outer cover	W_A	3900 lbs.	2	.0200
Gas cells	W_B	8860 ,,	2	.0455
Longitudinals	$W_{C1}+W_{C2}$	8000 ,,	4	.0823
Corridor	W_{C3}	3000 ,,	4	.0308
Transverses, main	W_{D1}	5200 ,,	4	.0534
Transverses, intermediate ...	W_{D2}	2450 ,,	4	.0252
Shear wires	W_E	1140 ,,	4	.0117
Transverse wires	W_F	1100 ,,	4	.0113
Netting and axial wire ...	W_G	2260 ,,	4	.0232
Tail surfaces	W_H	1800 ,,	3	.0139
Minimum ballast, hull fittings and controls	W_I	9500 ,,	3	.0731
Machinery	W_J	12000 ,,	2	.0616
Fuel and tanks	W_K	58990 ,,	2	.3030
Miscellaneous	W_L	6000 ,,	2	.0308
Armament, radio and control car	θ	5600 ,,	0	0
		129800 lbs.	$\Sigma xW_z/3W$ =	.7858

$$N = 1/(1 - .7858) = 4.67.$$

To carry the additional 2,000lbs. of bombs, without loss in other characteristics, the displacement must increase, by equation (8),

$$\Delta W = N\Delta\theta = 4.67 \times 2000 = 9330 \text{ lbs.}$$

Similarly, the increase in the weight of outer cover requires:—

$$\Delta W = NW_A \Delta a/a = 4560 \text{ lbs.}$$

The saving due to 15 per cent. reduction in weight of hull structural girders and frames is:—

$$\Delta W = -.15 (W_{D1} + W_{C1} + W_{C2}) N = 9250 \text{ lbs.}$$

To accomplish the 5 per cent. increase in speed we must provide more powerful machinery and somewhat stronger fins and rudders. Then by equation (8),

$$\Delta W_J = 3NW_J \Delta V/V, \text{ and}$$
$$\Delta W_H = 2NW_H \Delta V/V, \text{ or}$$
$$\Delta W = N \Delta V/V (3W_J + 2W_H) = 9248$$

It is here assumed that the cruising speed remains the same, so that no increase in fuel weight is required.

The total displacement of the ship due to changes a, b, c and d is now increased by 13,890lbs. net, giving $W = 143{,}690$lbs.

To obtain the weight statement for the new ship we may operate on each weight group by means of equation (7), which gives the following table:—

CALCULATION OF NEW WEIGHT STATEMENT AFTER CHANGES a, b, c and d.

Item.	Symbol.	Weight.
Outer cover	W_A	5150 lbs.
Gas bags	W_B	9490 ,,
Longitudinals	$W_{C1} + W_{C2}$	7940 ,,
Corridor	W_{C3}	3430 ,,
Transverses, main	W_{D1}	5160 ,,
Transverses, intermediate	W_{D2}	2800 ,,
Shear wires	W_E	1300 ,,
Transverse wires	W_F	1260 ,,
Netting and axial wire	W_G	2590 ,,
Surfaces	W_H	2170 ,,
Fittings	W_I	10500 ,,
Machinery	W_J	14680 ,,
Fuel and tanks	W_K	63150 ,,
Miscellaneous	W_L	6430 ,,
Armament, etc.	θ	7600 ,,
		143650 ,,
		143690 ,,
	Discrepancy	— 40 ,,

The change in length, or any linear dimension, is by equation (6):—

$$\Delta L/L = \tfrac{1}{3} \Delta W/W = .0356,$$

and the new length is 665ft., diameter 81.5ft., and volume 2,145,000 cu. ft.

Consider now the effect of a change in L/D from 8 to 6.85 while the volume remains constant. This is accomplished by reducing L 10 per cent. and increasing D 5 per cent. Also, suppose by this change the resistance coefficient (per unit of volume) is reduced 1 per cent.

By equation (3), the saving in weight due to change of form is:—

$$\Delta W = (\Delta L/L) \Sigma W_z (x - y/2)$$
$$= -.10 \times 14{,}770 = 1{,}477\text{lbs.}$$

The quantity $\Sigma W_z (x - y/2)$ is computed in the following table where the original weight statement has been used. It will be shown later that this procedure is not entirely correct but sufficiently exact for the purpose.

CALCULATION OF $\Sigma W_z (x - y/2)$ FOR L-49 TYPE.

Item.	Weight.	x.	y.	$W_z (x - y/2)$.	
Outer cover	3900	1	1	1950	
Gas bag sides	4430	1	1	2215	
Gas bag ends	4430	0	2		— 4430
Longitudinals	8000	3	1	20000	
Corridor	3000	3	1	7500	
Transverses (main) ...	5200	0	4		— 10400
Transverses (intermed.) ...	2450	1	3		— 1225
Shear wires	1140	2	2	1140	
Transverse wires... ...	1100	0	4		— 2200
Netting and axial wire ...	2260	1	3		— 1130
Tail surfaces	1800	1-1/2	1-1/2	1350	
Hull fittings	9500	1	2	0	
Machinery	12000	2/3	4/3	0	
Fuel and tanks	58090	2/3	4/3	0	
Miscellaneous	6000	2/3	4/3	0	
Armament, etc.	5600	0	0	0	
	129800			$\Sigma W_z (x - y/2) = 14770$	

In addition to this saving in weight the reduction of 1 per cent. in resistance coefficient, which appears only in W_J and W_K, permits a saving of 1 per cent. in these items or

$$-.01 (W_K + W_J) = -780\text{lbs.}$$

Here the values of W_K and W_J are those for the ship after changes a, b, c and d. The total saving in the ship is hence the sum, or 2,257lbs., which may be added to the independent load for a ship of the constant volume chosen, 2,145,000 cu. ft.

We now have a larger ship than the original L-49 model with over a ton more useful load than is needed to meet the specified characteristics. Let us now reduce the volume of the ship by eliminating this 2,257lbs. which has been saved. The lift of a new ship of the same geometrical form and performance characteristics can be reduced by N times this quantity, or

$$\Delta W = N\Delta\theta = 4.67 (2257) = 10{,}520\text{lbs.}$$

The corresponding reduction in L is

$$\Delta L/L = \tfrac{1}{3} \Delta W/W = 10{,}520/3 \times 143{,}690 = -.0244$$

and the new dimensions are:—

$$L = 665 \times .9 (1 - .0244) = 584\text{ft.}$$

$$D = 81.5 \times 1.05 (1 - .0244) = 83.5\text{ft.}$$

$$W = 133{,}170\text{lbs. or } 1{,}990{,}000 \text{ cu. ft.}$$

It might be objected at this point, that W and $\Sigma W_z (x - y/2)$ calculated for the original L-49 model have been used here for a ship that has grown considerably in the meantime. To check this, N and $\Sigma W_z (x - y/2)$ are calculated below

for the larger ship. Also, the L/D has actually come out 6.99 instead of the 6.85 first proposed.

CALCULATION OF N IN ENLARGED AIRSHIP.

Symbol.	Weight.		x.	$xW_z/3W$.
W_A	5150	= 14640	2	.0680
W_B	9490		2	
$W_{C1} + W_{C2}$ ...	7940		4	
W_{C3}	3430		4	
W_{D1}	5160		4	
W_{D2}	2800	= 24480	4	.228
W_E	1300		4	
W_F	1260		4	
W_G	2590		4	
W_H	2170	= 12670	3	.0882
W_I	10500		3	
W_J	14680		2	
W_K	63150	= 84260	2	.3931
W_L	6430		2	
θ	7000	6700	0	0
	143650			.777

$N = 1/1 - .777 = 4.48$ as compared with
$N = 4.67$ in original airship.

CALCULATION OF $W_z(x - y/2)$ FOR ENLARGED AIRSHIP.

Symbol.	Weight.	x.	y.	$W_z(x - y/2)$.
W_A	5150	1	1	2575
W_{B1}	4795	1	1	2373
W_{B2}	4745	0	2	— 4745
$W_{C1} + W_{C2}$ ...	7940	3	1	19850
W_{C3}	3430	3	1	8570
W_{D1}	5160	0	4	— 10320
W_{D2}	2800	1	3	— 1400
W_E	1300	2	2	1300
W_F	1260	0	4	— 2520
W_G	2590	1	3	— 1295
W_H	2170	1–1/2	1–1/2	1645
W_I	10500	1	2	0
W_J	14680	2/3	4/3	0
W_K	63150	2/3	4/3	0
W_L	6430	2/3	4/3	0
θ	7600	0	0	0
	143650	$\Sigma W_z(x - y/2) = +$ 16033lbs.		

The change from a length of 665ft. to 584ft., as calculated above, involves two steps; first, a change in length of 10 per cent. while volume is constant; and second, a reduction in volume keeping similitude with a further change in length. Due to the first cause, we have

$$\Delta W = (\Delta L/L)\,\Sigma W_z\,(x - y/2) = -.10\ (16033) = -1603\text{lbs.}$$

We also have the same saving of 780lbs. in machinery and fuel. The total saving in the ship is then 2,383lbs. and the ship may be reduced geometrically in lift or displacement by

$$\Delta W = N\Delta\theta = -4.48\ (2383) = -10670\text{lbs.}$$

This is to be compared with 10,520lbs. computed before, using the old values of N and $\Sigma W_z\,(x - y/2)$. The difference is unimportant for preliminary design studies where Normand's methods might be useful.

By applying the same method further, we obtain the following weight statement for the altered ship:—

WEIGHT STATEMENT FOR FAT AIRSHIP COMPARED WITH ORIGINAL.

Original.			Revised.
3900	Outer cover	= (5220 × .952) — 261	= 4700 lbs.
4430	Gas bag sides ...	= (4735 × .952) — 237	= 4263 ,,
4430	Gas bag ends... ...	= (4735 × .952) + 473	= 4973 ,,
8000	Longitudinals	= (7790 × .906) — 1948	= 5102 ,,
3000	Corridor	= (3440 × .906) — 860	= 2260 ,,
5200	Transverse, main ...	= (5060 × .906) + 1012	= 5600 ,,
2450	Transverse, intermed.	= (2800 × .906) + 140	= 2680 ,,
1140	Shear wires	= (1305 × .906) — 130	= 1052 ,,
1100	Transverse wires ...	= (1260 × .906) + 252	= 1393 ,,
2260	Netting	= (2590 × .906) + 130	= 2480 ,,
1800	Surfaces	= (2195 × .929) — 164	= 1876 ,,
9500	Fittings	= 10510 × .929	= 9760 ,,
12000	Machinery	= 14850 × .99 × .952	= 14000 ,,
58990	Fuel and tanks ...	= 63100 × .99 × .952	= 59500 ,,
6000	Miscellaneous	= 6420 × .952	= 6110 ,,
5600	Armament, etc. ...	= 7600	= 7600 ,,
129800 lbs.		Total weight	= 133349 lbs.

as compared with 133,170lbs. expected.

The changes in displacement which the type ship has gone through as a result of the successive alterations proposed are summarised in the following figure:—

Original	L:643 ft. D:78.7 "	1,940,000 cu.ft.
Plus additional 2,000 lb. bombs	L:657 " D:80.5 "	2,080,000 cu.ft.
and 25% heavier cover fabric	L:665 " D:81.5 "	2,145,000 cu.ft.
and 15% saved on longitudinals and main transverses	L:650 " D:79.6 "	2,008,000 cu.ft.
and 5% more speed	L:665 " D:81.5 "	2,145,000 cu.ft.
and Length/Diameter reduced from 8 to 7	L:584 " D:83.5 "	1,990,000 cu.ft.

FIG. 1.

APPENDIX IV.

Limitations of the Method.

The manner of obtaining approximate expressions for each member of the weight equation is based upon similarity of structure and general type of construction. In particular, the number of gas bags and girders remains constant. For such changes in displacement as are caused by reasonable alterations in the design characteristics (the independent variables) this will be the case. It is considered that a 25 per cent. variation in displacement would not be exceeded.

The differentiation used is based on an approximation to the exact form :—

$$(W_z + \Delta W_z) = K\,(L + \Delta L)^x\,(D + \Delta D)^y\,(a + \Delta a)^w \text{ (etc.)},$$

which, when expanded, contains higher powers of the increments ΔL, ΔD, Δa, etc. These have been neglected. Naturally, these increments must be small if the error made is to be small.

Professor Hovgaard[1] has shown, for warships, that to obtain useful accuracy, the displacement should not change more than 25 per cent., and other factors which occur only in the first power (a, b, f, t, etc.) not more than 10 per cent. There should also be a restriction that there be changed not more than one variable in any one term. For airships similar restrictions obviously apply.

On the face of the weight equation, there seems to be no reason to limit it to ships of any displacement whatever, provided similitude is retained. However, there would be little practical value in expanding the weight equation for a two million cubic foot airship to furnish a weight statement for a ten million cubic foot airship. No designer would preserve similitude. The larger ship would surely be built with a more advantageous arrangement of girders, a different number of cells, and in general a different general design.

Mr. Campbell[2] does, however, expand a weight equation for a small airship to apply to a very large one, but does not appear to assume structural similitude. Some of the weight groups which I have here assumed to vary as L^4 he takes as increasing only as L^3. In particular, Mr. Campbell assumes the longitudinal girder weight to depend on the distribution of concentrated loads which might possibly be better spread out in the large ship. Such a practical consideration, of course, cannot be expressed in mathematical form, as it is entirely a matter of speculation.

APPENDIX V.*

The Model Basin in Aeronautics.

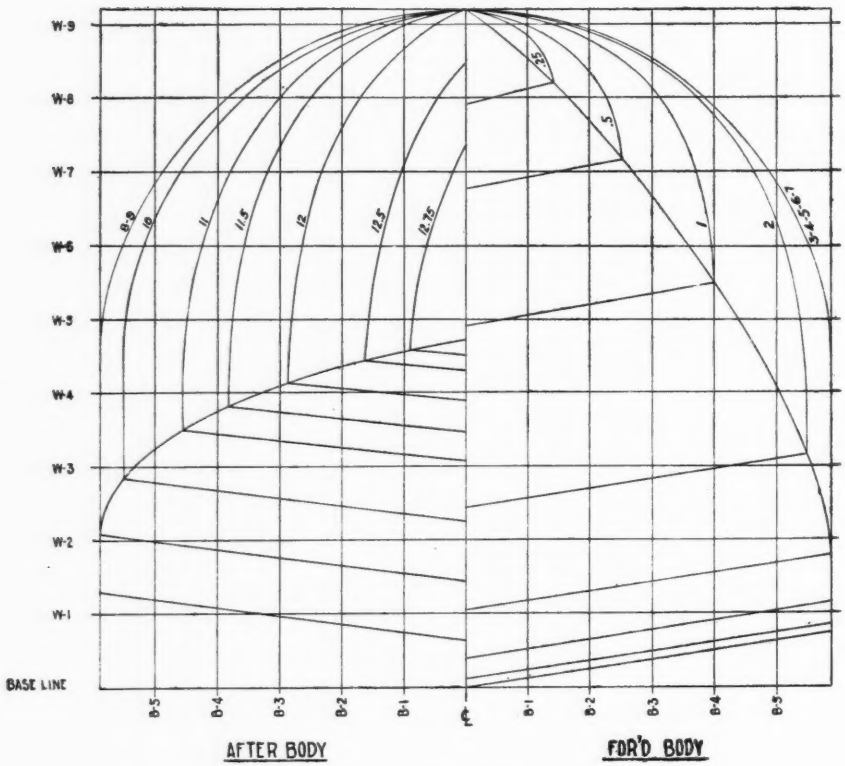
The most direct application of the methods of the naval architect in aeronautics lies in the use of the model basin. The model basin of Froude has been developed in all maritime countries and the existing methods and apparatus were immediately available and it was necessary only to determine whether Froude's law of corresponding speeds applied to planing action in order to employ model tests to judge the relative merits of different forms of planing bottoms. This verification has been very satisfactorily demonstrated by the successful performance of seaplanes designed from the results of tank experiments on models. I

(1) W. Hovgaard, "General Design of Warships," Spon, London, 1920.
(2) C. R. Campbell, "Inst. Nav. Arch.," London, March, 1920.

* I am indebted to my assistant, Lieut. C. B. Harper, for help in the preparation of this Appendix.

FIG. 1
SEAPLANE-FLOAT.

MODEL Nº 2103-B.



BODY PLAN

Appendix V.

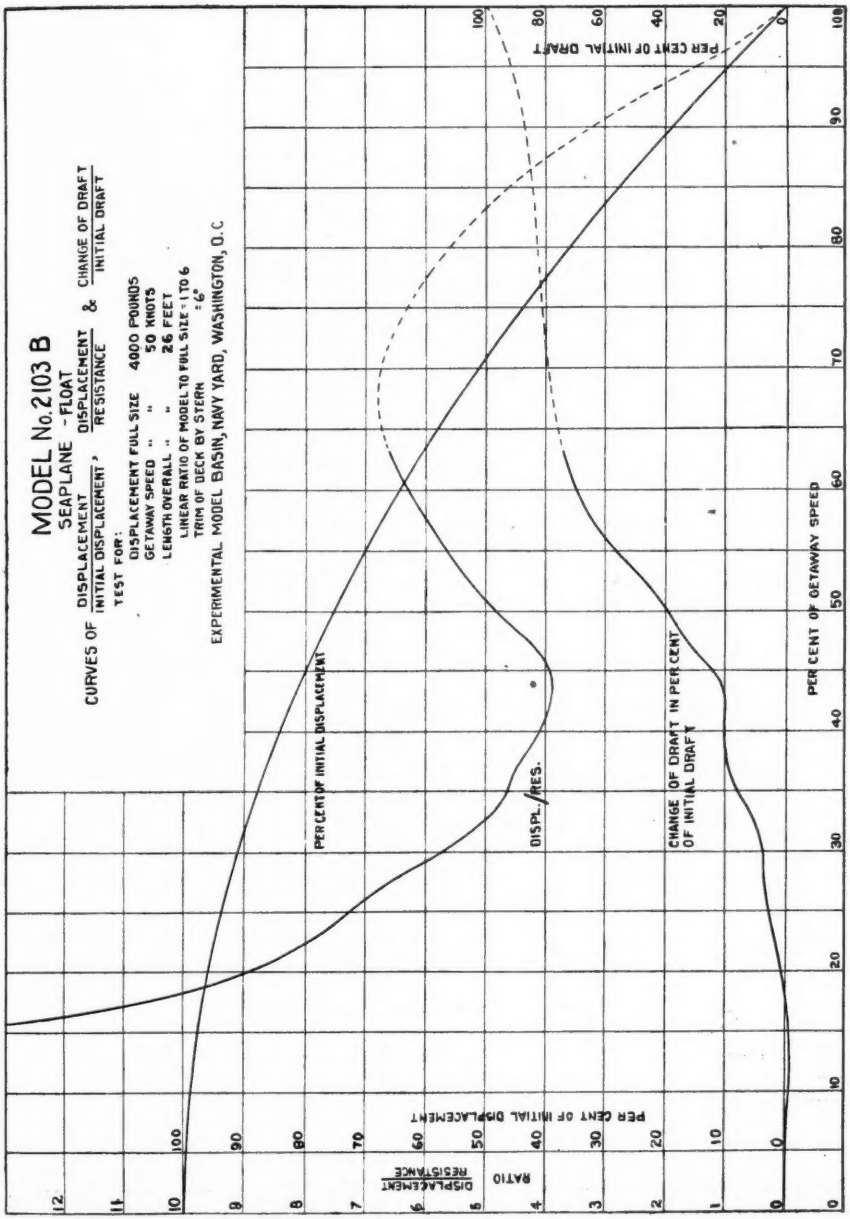

MODEL No. 2103 B
SEAPLANE - FLOAT
CURVES OF DISPLACEMENT / INITIAL DISPLACEMENT², DISPLACEMENT / RESISTANCE & CHANGE OF DRAFT / INITIAL DRAFT
TEST FOR:
DISPLACEMENT FULL SIZE 4000 POUNDS
GETAWAY SPEED " " 50 KNOTS
LENGTH OVERALL " " 26 FEET
LINEAR RATIO OF MODEL TO FULL SIZE = 1 TO 6
TRIM OF DECK BY STERN = 6°
EXPERIMENTAL MODEL BASIN, NAVY YARD, WASHINGTON, D.C
PER CENT OF INITIAL DISPLACEMENT
PERCENT OF INITIAL DISPLACEMENT
DISPL./RES.
CHANGE OF DRAFT IN PERCENT OF INITIAL DRAFT
PER CENT OF INITIAL DRAFT
PER CENT OF GETAWAY SPEED
RATIO DISPLACEMENT / RESISTANCE

FIG. 2

APPENDIX V.

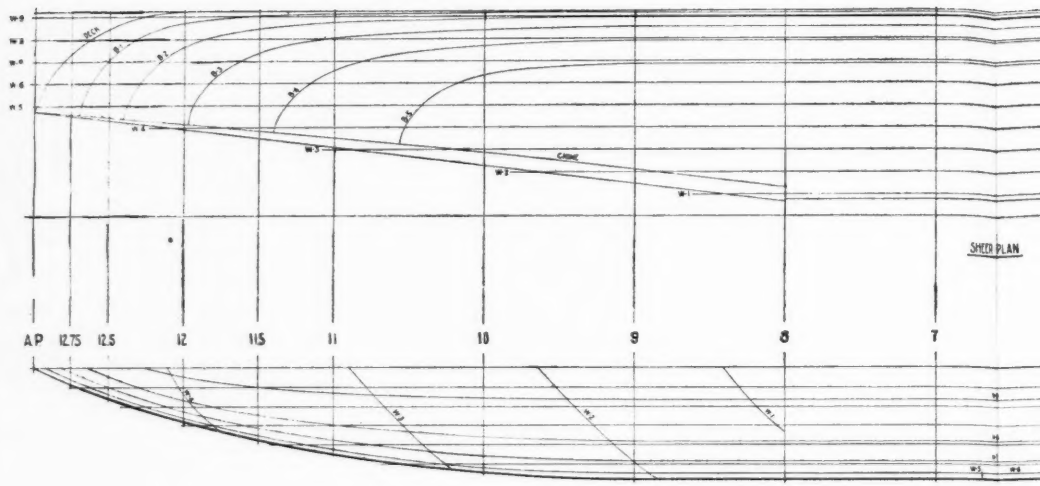


FIG. 1.
APPENDIX V.

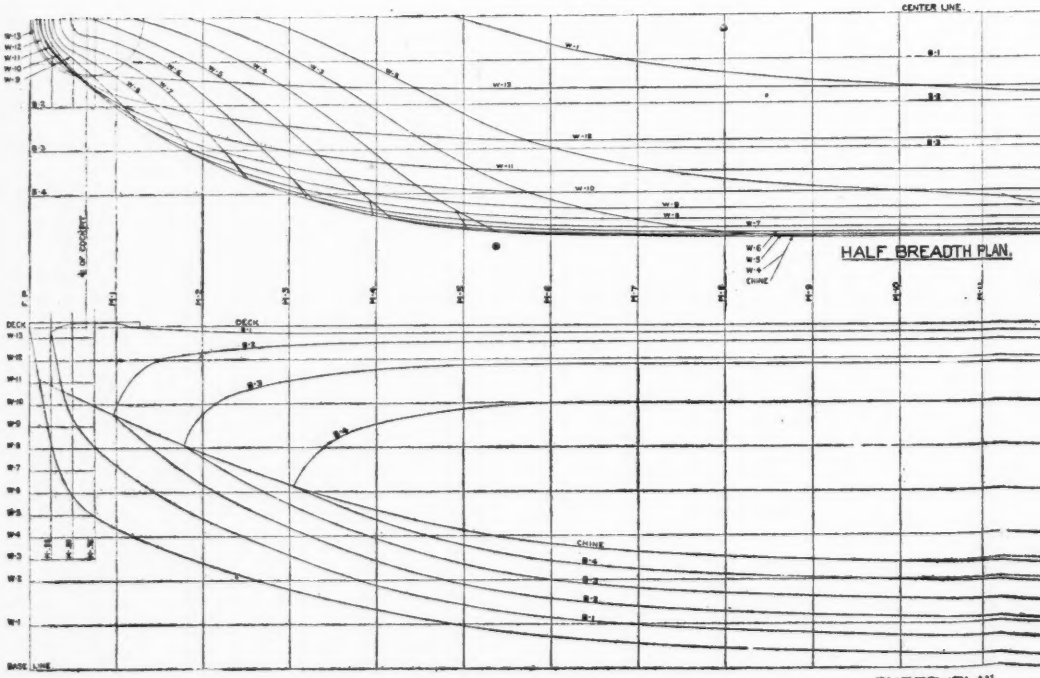
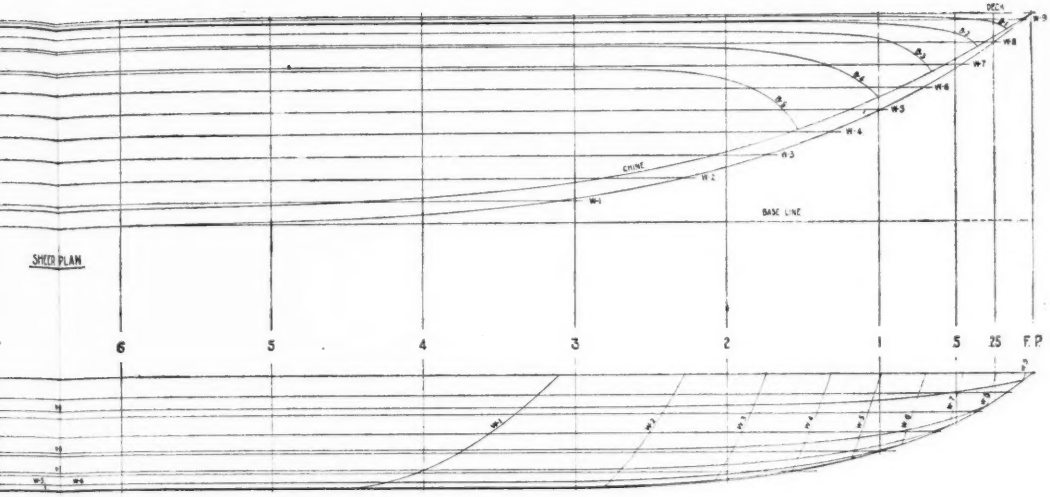
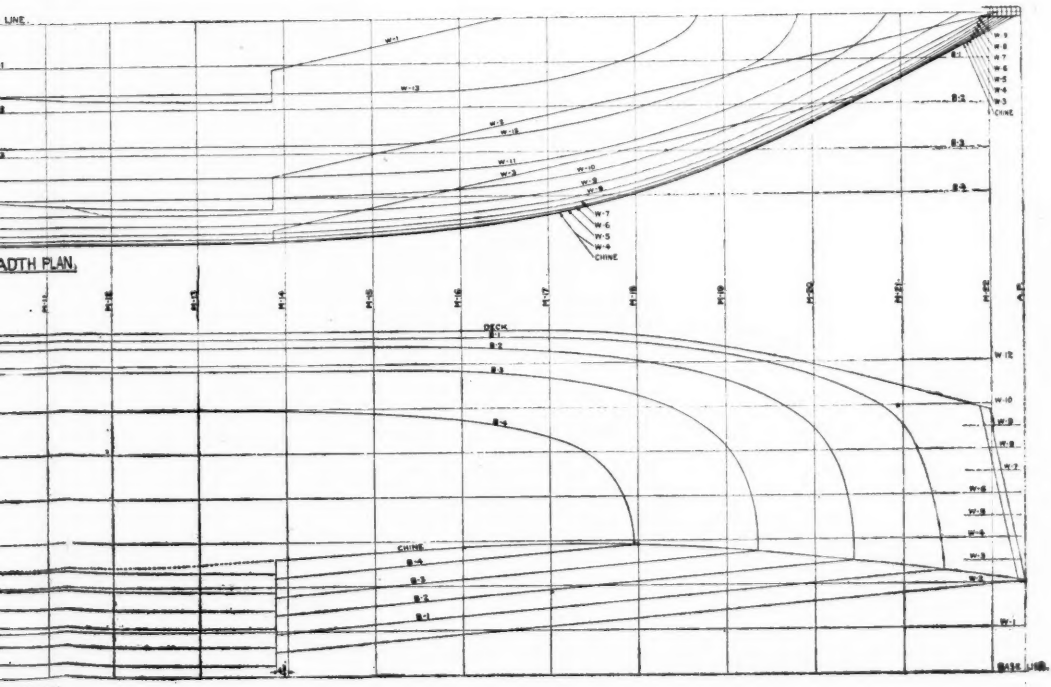


FIG. 3.
APPENDIX V.



HALF BREADTH PLAN

FIG. I.
PPENDIX V.

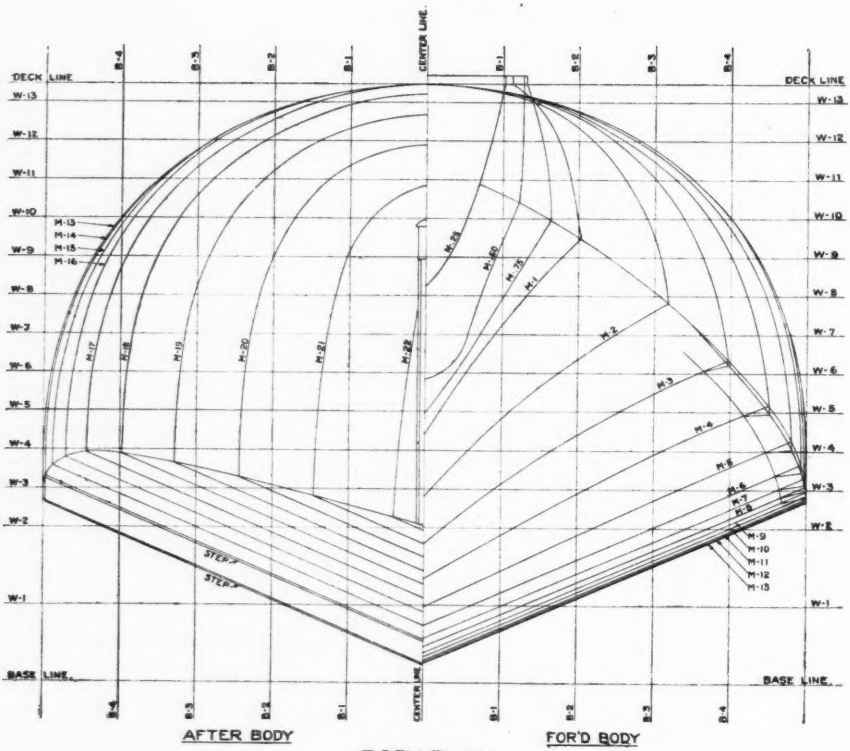


R PLAN.

IG. 3.
ENDIX V.

FIG. 3
SEAPLANE-BOAT.

MODEL Nº 2081-C.



BODY PLAN.

APPENDIX V.

need not go into specific examples, as the general facts are well established,[1] but I can say that commencing with the experiments of Commander H. C. Richardson, C.C., U.S.N., at the Washington Navy Yard in 1915, and continuing with the more recent work at the tank of Commander Wm. McEntee, C.C., U.S.N., our experience gained in the design of a large number of flying boat hulls and floats uniformly shows full scale results entirely in concordance with the prediction made from tests with models. This concordance is the more firmly established from our having used the same form of float developed in the tank for both large and small seaplanes.

At the present time we would not think of building a flying boat hull without data from the model basin. In a few isolated cases when haste or some less plausible reason has forced a lapse in this policy we have been disappointed.

As a result of having built many seaplanes and tested very many more in the tank, there have been developed a few forms which are for all-round purposes superior to the others. I trust that some day Commanders Richardson and McEntee may collect and analyse their work of the past four years and publish the results for the benefit of the art. I am very happy, however, to take this occasion to publish, with the permission of the Chief Constructor, Rear-Admiral D. W. Taylor, C.C., U.S. Navy, the lines of two of the best of these, one a float or pontoon which has been used on both single and twin float seaplanes, and the other the hull used for the N.C. flying boats.

The vee-bottom floats are strong and of good behaviour in rough water, but they have one fault in that an excessive amount of spray is thrown out at the "hump speed" just before planing is established. This is of consequence in twin float seaplanes with a low propeller. With a view to saving the propeller, Mr. G. C. Loening has proposed "split" floats having the bottoms slanting outboard, the general scheme being similar to an experiment made, I understand, during the war at the R.A.F. Experimental Station, Grain. Such floats appear effectively to keep spray out of the propeller, but are about twice as hard to drive as the ordinary vee-bottom type. No doubt improvements can be made to reduce resistance. A tank run on a pair of such floats is shown in Fig. 5 where the wire marks the propeller disc.

A means for recording and studying the formation of waves and spray has recently been developed, using the ultra-rapid motion picture camera. A picture taken at eight times the speed of the commercial machine when projected at ordinary speed (16 per second) gives a view of the whole phenomenon to a microscopic time scale. Pictures made of the tank tests are available for study at leisure by designers who are unable to be present at the trials and permit a detailed inspection of the complex and ever changing movements of the water.

Fig. 6 is an enlargement from the film taken of Model 2081-C at the hump speed. The spray is thrown off to either side in a continuous sheet.

Fig. 7 is a photograph of the full size flying boat at corresponding speed (taken to include the horizon so as to give the inclination). It is noted that the spray is broken up and no longer exists as a continuous sheet as in the model tests.

An application of the towing basin without precedent in naval architecture is the strength testing of aeroplane wing ribs. The full size ribs are built into a short section of wing with false ribs on the ends and covered with doped fabric fastened in the method actually to be used. Rectangular plates are secured to the ends to cut off water spilling around the edges. The panel is towed submerged at such a depth that surface waves do not appear until failure is reached.

(1) H. C. Richardson, Society Naval Architects and Marine Engineers, New York, Nov., 1916. G. S. Baker, "Flying Boats," etc., North-East Coast Institution of Engineers and Shipbuilders, Newcastle, February 27, 1920.

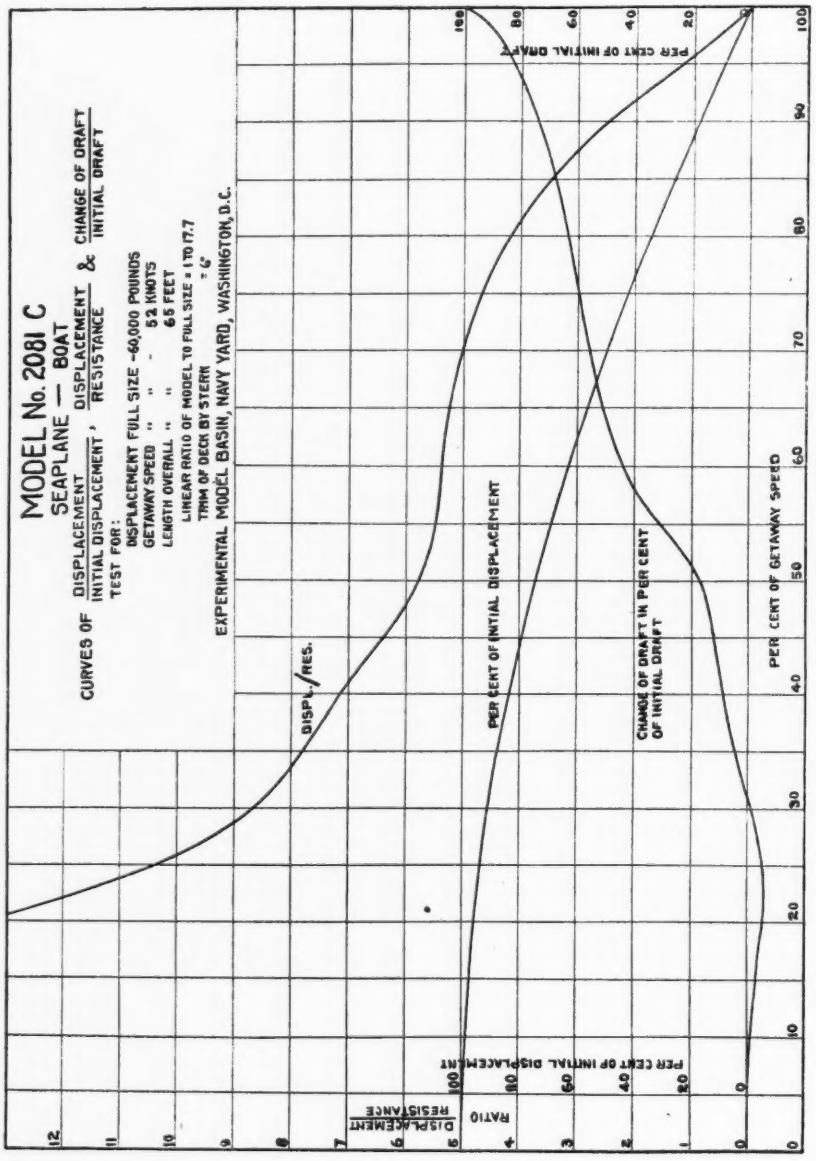

MODEL No. 2081 C
SEAPLANE — BOAT
CURVES OF DISPLACEMENT / INITIAL DISPLACEMENT, DISPLACEMENT / RESISTANCE & CHANGE OF DRAFT / INITIAL DRAFT
TEST FOR:
DISPLACEMENT FULL SIZE -60,000 POUNDS
GETAWAY SPEED " " - 52 KNOTS
LENGTH OVERALL " " 65 FEET
LINEAR RATIO OF MODEL TO FULL SIZE = 1 TO 17.7
TRIM OF DECK BY STERN = 6°
EXPERIMENTAL MODEL BASIN, NAVY YARD, WASHINGTON, D.C.
DISPL./RES.
PER CENT OF INITIAL DISPLACEMENT
CHANGE OF DRAFT IN PER CENT OF INITIAL DRAFT
PER CENT OF INITIAL DRAFT
PER CENT OF GETAWAY SPEED
DISPLACEMENT / RESISTANCE
RATIO
PER CENT OF INITIAL DISPLACEMENT

FIG. 4
APPENDIX V.

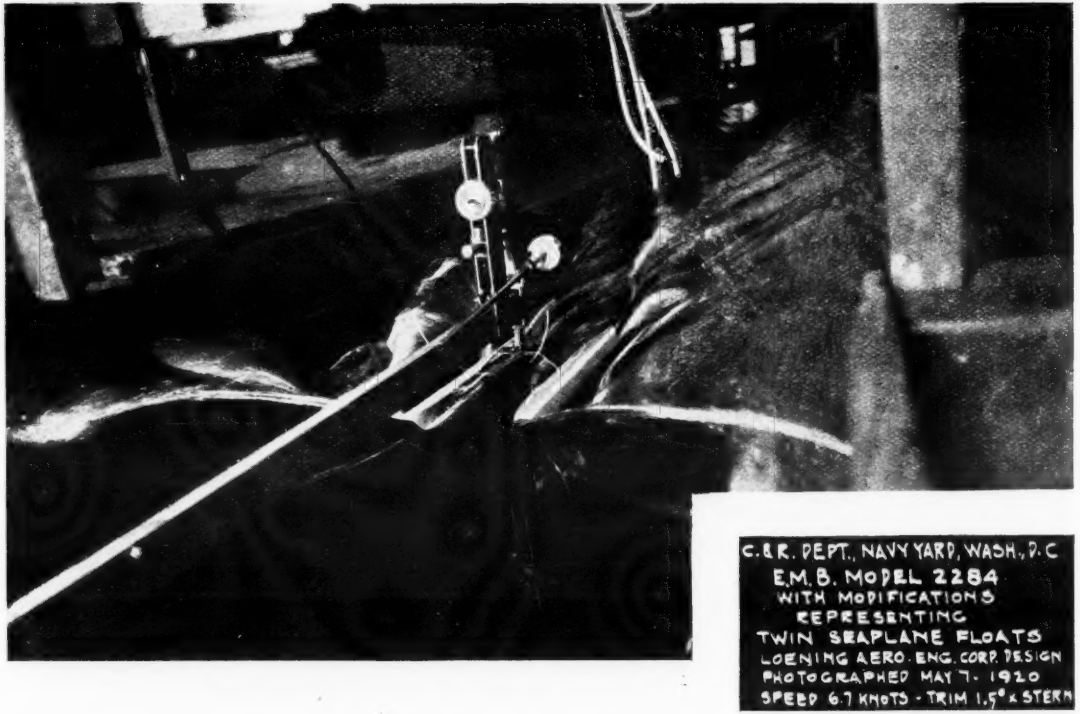

C.&R. DEPT., NAVY YARD, WASH., D.C
E.M.B. MODEL 2284
WITH MODIFICATIONS
REPRESENTING
TWIN SEAPLANE FLOATS
LOENING AERO. ENG. CORP. DESIGN
PHOTOGRAPHED MAY 7. 1920
SPEED 6.7 KNOTS - TRIM 1.5° x STERN

FIG. 5.
APPENDIX V.

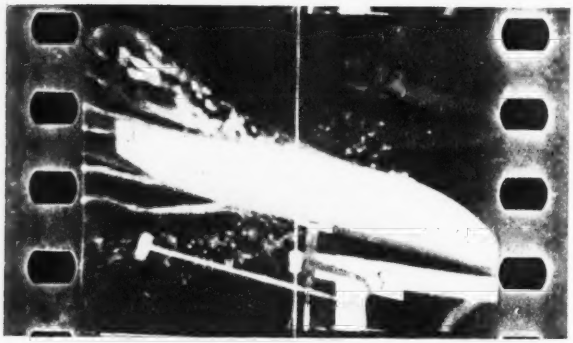


FIG. 6.
APPENDIX V.

FIG. 7.
APPENDIX V.

Appendix V.
Table I.

TABLE OF OFFSETS

HEIGHTS					HALF BREADTHS																				
					BUTTOCKS DECK				BUTTOCKS BOTTOM				WATER LINES												
Moulds	Bottom of Planking	Chine	Deck	Spray Strip	B-12	B-24	B-36	B-48	B-12	B-24	B-36	B-48	Chine	W.L.12	W.L.24	W.L.30	W.L.36	W.L.42	W.L.48	W.L.54	W.L.60	W.L.66	W.L.72	W.L.78	W.L.84	W.L.90	Moulds
F.P.			134.7																						F.P.
M-.25	89.2	117.2	"		133.2								12.0									4.4	9.2	12.3	15.1	16.9	M-.25
M-.50	68.3	108.0	"		136.5				99.0				21.0						3.4	9.6	12.5	16.0	19.6	21.6	21.9	22.1	M-.50
M-.75	60.5	102.9	"		136.5				86.6				28.6					.2	6.9	12.3	17.6	23.0	26.5	26.1	26.8	24.1	M-.75
M-1	55.5	99.9	"		136.5	193.5			80.3				35.3					3.3	9.3	17.2	22.8	31.0	34.6	33.2	30.0	24.7	M-1
M-2	41.9	85.2	"	85.2	133.0	124.5	100.4		59.3	72.7	83.4		55.5			1.5	8.8	19.2	30.4	43.4	55.1	53.7	50.6	45.3	38.1	24.8	M-2
M-3	31.4	72.5	"	71.6	133.2	127.1	113.5		44.6	55.5	64.9		69.2		4.4	15.8	29.0	44.4	62.3	68.2	65.4	63.3	58.8	52.6	43.0	26.8	M-3
M-4	23.2	62.4	"	60.4	"	128.1	117.8	96.2	33.0	42.4	51.3	58.9	76.3		20.7	36.8	54.2	74.5	77.6	76.0	73.4	69.8	64.5	57.3	46.4	28.1	M-4
M-5	17.0	54.4	"	52.4	"	128.5	119.3	102.0	25.0	33.2	41.0	48.6	83.6	.7	38.6	58.0	78.2	83.2	82.1	80.4	77.5	73.3	67.8	59.8	48.0	28.6	M-5
M-6	12.7	49.1	"	47.1	"	128.5	119.8	104.4	20.1	27.6	34.8	42.2	85.7	11.2	51.8	72.2	85.4	85.4	84.2	82.5	79.6	75.4	69.6	61.1	49.0	"	M-6
M-7	10.0	45.9	"	44.0	"	"	"	"	17.2	24.5	31.7	39.0	86.5	18.1	59.6	80.5	85.3	85.9	85.1	83.2	80.1	75.7	"	"	"	"	M-7
M-8	8.2	44.0	"	43.0	"	"	"	"	15.2	22.5	29.7	37.1	86.8	22.8	54.5	85.4	86.7	86.3	85.4	83.2	"	"	"	"	"	"	M-8
M-9	6.7	43.0	"	42.4	"	"	"	"	14.0	21.2	28.5	35.7	87.0	25.9	67.4	87.0	86.9	86.5	85.4	"	"	"	"	"	"	"	M-9
M-10	5.8	42.1	"	42.1	"	"	"	"	13.1	20.3	27.6	34.8	"	28.1	69.6	"	78.0	"	"	"	"	"	"	"	"	"	M-10
M-11	5.1	41.3 42.1	"		"	"	"	"	12.3	19.6	26.8	34.1	"	29.9	70.2	"	"	"	"	"	"	"	"	"	"	"	M-11
M-12	4.5	40.8 42.6	"		"	"	"	"	11.8	19.0	26.3	33.5	"	31.0	72.8	"	"	"	"	"	"	"	"	"	"	"	M-12
M-13	4.5	40.6 43.9	"		"	"	"	"	11.6	18.9	26.1	33.4	"	31.7	73.1	"	"	"	"	"	"	"	"	"	"	"	M-13
Step	4.2 9.4	40.2 45.5	"		"	"	"	104.0	11.4 16.5	18.7 23.7	25.9 31.0	33.2 38.2	86.6	31.9 19.4	73.6 61.0	86.7 81.9	86.7	86.1	84.8	82.8	79.7	75.2	69.2	"	"	"	Step
M-14	9.8	45.7	"		"	"	"	103.9	17.0	24.3	31.5	38.5	85.5	18.3	60.0	80.9	85.4	85.9	84.8	82.7	79.6	75.2	69.2	60.9	"	"	M-14
M-15	12.9	48.0	"		"	"	119.6	102.8	20.1	27.4	34.6	41.9	84.8	10.9	52.[illegible]	73.5	84.9	84.3	83.2	81.2	78.3	74.1	68.3	60.4	48.9	"	M-15
M-16	15.0	50.0	"		"	128.1	118.9	100.[illegible]	83.2	30.5	37.7	45.0	81.7	3.4	45.2	66.0	81.8	81.3	80.3	78.5	76.1	72.1	66.7	58.7	47.7	28.5	M-16
M-17	19.0	51.1	"		132.3	126.5	116.0	93.0	26.3	33.5	40.8	48.0	77.0		37.7	65.8	77.0	76.7	76.0	74.1	71.8	68.3	62.9	55.3	43.5	24.7	M-17
M-18	22.1	50.8	132.5		130.0	122.7	109.3		29.4	36.6	43.9		69.1		30.5	51.3	69.2	68.6	68.2	66.7	64.8	61.3	56.2	48.2	36.3	15.1	M-18
M-19	25.2	48.9	127.8		124.9	115.1	89.2		32.4	39.7	46.9		57.1		23.2	43.8	56.9	56.7	56.0	54.9	52.9	49.7	44.6	37.0	24.3		M-19
M-20	28.3	45.9	120.7		116.4	95.7			35.5	42.8			42.2		15.8	36.4	42.2	41.9	41.1	39.9	37.8	34.8	30.1	22.3			M-20
M-21	31.2	42.9	111.7		96.8				36.4				25.4		8.3	25.2	24.8	24.3	23.6	22.1	20.3	18.0	12.5				M-21
M-22	34.4	37.3											7.1		.9		5.9	4.9	4.9	2.5							M-22
Stern	35.6	35.5	102.4										1.6			1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6				Stern

NOTE.—*All dimensions are in inches and tenths of inches to outside of planking. Heights are measured from base line, half breadths are measured from centre line.*

TABLE II.

TABLE OF OFFSETS

HEIGHTS									HALF BREADTHS										
					BUTTOCKS				WATER LINES										
MOULDS	BOTTOM OF PL'KING	CHINE	DECK AT C.L.	B-1	B-2	B-3	B-4	B-5	CHINE	W-1	W-2	W-3	W-4	W-5	W-6	W-7	W-8	W-9	MOULDS
F.P	32.2																		
M- .25	27.8	28.6	32.2	28.4					4.3								1.4	2.2	M- .25
M- .50	23.6	25.0	32.2	24.3	24.7				7.5							4.4	6.8	2.6	M- .50
M- 1.	17.3	19.1	32.2	15.6	18.1	18.6	19.1		12.0					1.8	11.9	11.1	9.4	4.1	M- 1.
M- 2.	8.6	11.0	32.2	8.9	9.4	9.9	10.3	10.6	16.5			12.7	16.4	16.1	15.4	13.9	11.1	4.8	M- 2.
M- 3.	3.7	6.3	32.2	4.1	4.5	5.0	5.4	5.9	17.6		17.6	17.6	17.6	17.5	16.5	14.6	11.5	5.1	M- 3.
M- 4.	1.4	4.0	32.2	1.8	2.3	2.7	3.2	3.6	17.6	12.3	17.6	17.6	17.6	17.5	16.5	14.6	11.5	5.1	M- 4.
M- 5.	0.4	2.9	32.2	0.8	1.3	1.7	2.1	2.6	17.6		17.6	17.6	17.6	17.5	16.5	14.6	11.5	5.1	M- 5.
M- 6.		2.6	32.2	0.4	0.9	1.3	1.8	2.2	17.6		17.6	17.6	17.6	17.5	16.5	14.6	11.5	5.1	M- 6.
M- 7.		2.6	32.2	0.4	0.9	1.3	1.8	2.2	17.6		17.6	17.6	17.6	17.5	16.5	14.6	11.5	5.1	M- 7.
M- 8.	2.3	4.5	32.2	2.6	3.0	3.4	3.8	4.1	17.6	9.9		17.6	17.6	17.5	16.5	14.6	11.5	5.1	M- 8.
M- 9.	5.0	7.3	32.2	5.4	5.8	6.2	6.5	6.9	17.6		15.4	17.6	17.6	17.5	16.5	14.6	11.5	5.1	M- 9.
M-10.	7.9	9.9	32.2	8.2	8.6	9.0	9.3	9.7	16.5				16.6	16.4	15.6	13.7	10.7	4.4	M-10.
M-11.	10.7	12.3	32.2	11.1	11.4	11.7	12.0		13.6				13.7	13.5	12.7	11.4	9.0	3.6	M-11.
M-11.5	12.1	13.3	32.2	12.4	12.8	13.1			11.4				11.4	11.3	10.7	9.6	7.5	2.9	M-11.5
M-12.	13.5	14.4	32.2	13.8	14.2				8.6				3.8	8.4	7.9	6.9	5.1	1.4	M-12.
M-12.5	15.0	15.5	29.5	15.3					4.9					4.7	4.1	3.1	1.3		M-12.5
M-12.75	15.7	15.9	25.6						2.7					2.6	1.9	0.6			M-12.75
A.P.	16.5																		

NOTE.—*All dimensions are in inches and tenths of inches to outside of planking.*
Heights are measured from base line, half breadths are measured from centre line.

This method of loading tests ribs, fabric and lacing under correct conditions of pressure distribution.

An extension of the usual work of the model basin has led to an investigation of the strength of flying boat hulls to resist the shock of landing. For this purpose accelerometers are mounted on the keelson and at other points in the boat to record the shock of landing and to give an indication of the manner in which the shock is absorbed by the elasticity of the hull structure. The experiments are made full scale on the Potomac River near the Washington Navy Yard.

Two types of accelerometer are used, the R.A.F. instrument[1] and a spring type developed by Dr. Zahm.[2] The R.A.F. instrument is very satisfactory for recording loads imposed in the air by acrobatic flying, but it appears that the force at landing is too suddenly applied to be easily measured by this type of apparatus. The Zahm type depends only on the deflection of a series of light springs by a series of masses and gives a definite maximum.

Landings in smooth water were made with a Curtiss HS-2L flying boat, weight 6,400 pounds, 360 B.H.P., landing speed 55-60 miles per hour. The Zahm and R.A.F. instruments were mounted over the keelson at the transverse frame over the step and the following records obtained:—

Maximum vertical and horizontal forces as recorded by the Zahm accelerometer:—

Stall landing.	Vertical.	Horizontal.
	7W	2.5W
Speed landing.	Vertical.	Horizontal.
	7W	2.5W

As recorded by the R.A.F. accelerometer:—

Stall landing.	Vertical.	Horizontal.
	3.2W	1.1W
Speed landing.	Vertical.	Horizontal.
	3W	1.7W

It cannot be said that these landings were either very good or very bad from the pilot's point of view. The water was smooth and the conditions of the landings which have been recorded by moving pictures are such as ordinary service use requires. The points of interest brought out are, first, the very considerable horizontal component of the force and, second, the discrepancy between the Zahm and R.A.F. instruments. The readings of the R.A.F. instrument appear to be consistent with the maximum vertical force of 3.3W indicated by the measurements on models reported by Baker[3] for another type of boat hull.

From practice, the presence of intense landing shocks seems confirmed. The U.S. Navy has permitted a load factor of 8 for the design of pontoon struts and engine foundations on flying boats, but in several cases failure has resulted.

(1) Advisory Committee for Aeronautics, R. & M. 469.
(2) A. F. Zahm, "Journal of the Franklin Institute," Philadelphia, August, 1919.
(3) G. S. Baker, Advisory Committee for Aeronautics, R. & M. 583.

A NOTE ON THE THEORIES OF SCREW PROPULSION.

BY HENRY C. WATTS, D.SC., F.R.AE.S.

The object of this note is to draw attention to a misconception of the theory of screw propulsion which appears in much good work now being done.

This misconception lies in the combination of the Froude inflow theory and the Drzewiecki blade element theory used in conjunction with aerofoil characteristics obtained from tests in an air tunnel.

To explain further one must refer briefly to the various theories which are put forward to account, wholly or partially, for the behaviour of a screw propeller.

The theory and method of design in use for aircraft propellers is that due to Drzewiecki and modifications of it. The method in its simplest form consists in considering a tangential element of the blade as an aerofoil. Each element has a velocity relative to the air which is compounded of the forward velocity V of the propeller and a tangential velocity $v_1 = 2\pi rn$ due to its rotation

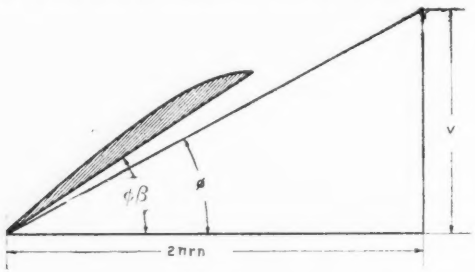


FIG. 1.

(see Fig. 1). If $\phi\beta$ = the angle made by the chord of the element with the plane of rotation and $\phi = \tan^{-1}(V/2\pi rn)$, then the angle of incidence of the elementary aerofoil to the relative air is $\phi\beta - \phi$. Knowing this angle, one can obtain the lift and drag of the element from the tests of the aerofoil in an air channel, and from this data it is a simple matter to deduce expressions for the thrust, torque and efficiency of the element and of the whole blade.

A modification of this method of examination is based on some conceptions due to R. E. Froude. It is supposed in Froude's theory that the propeller is replaced by and is equivalent to a special kind of disc moving at a velocity V relative to the air and having some means of imparting a steady pressure to the column of air passing through it. The column of air is assumed to be of streamline character in the sense that the value $p + 1/2\rho v^2$ remains constant at all points in the stream.

Under this condition the column of air will be subject to an acceleration for some distance in front of and behind the propeller disc and it is shown by equating the rate of change of momentum to the thrust that one half of the total increased air velocity due to the thrust takes place before the time the air reaches the actuating disc. Hence, if v = total increase in velocity of the air due to the thrust (usually termed the outflow velocity) then the axial speed of the air at the actuating disc or propeller is not V but $V + v/2$.

Dr. Stanton has shown by experiments at the National Physical Laboratory that Froude's assumption as to approximately streamline flow is fully justified as far as the inflow and the passage of the air through the disc is concerned.

At first sight it would therefore appear that in the blade element method the

assumption that the axial component of the relative air velocity is equal to the forward speed of the propeller is erroneous, and should be replaced by a value equal to $V + v/2$ or at least by a value equal to $V + xv$ where x is some constant less than unity.

This, however, is the misconception to which reference was made in the opening remarks. The inflow and outflow on a propeller is simply the flow of air caused by the lift and drag reactions on the aerofoil elements. It exists both when the aerofoil is tested in the wind channel or is used in the propeller blade. In the propeller it is a flow turning with the blade which (apart from the blade interference) continues to attack the air at an angle of incidence of $\phi\beta - \phi$.

Since no account is taken of the inflow when measuring the angle of incidence of an aerofoil in the air channel, none should be taken in applying the results to the aerofoil in the propeller blade.

Observations such as those of Dr. Stanton might perhaps throw doubt on the idea of a flow turning with the blade for this would mean a varying air velocity whilst his measurements gave the velocity at any one point as constant and agreeing well with the Froude assumptions.

It must, however, be borne in mind that all Dr. Stanton could measure was the average velocity at any given radius. If, for instance, a full size propeller rotates as 1,200 r.p.m. a model would rotate at about 2,400 r.p.m. The blades would thus pass the point at which measurements were being taken 80 times per sec. In such condition it is easy to see that a liquid manometer connecting the two ends of the pitot tube could only read a mean speed quite different from the real instantaneous speed. In order to measure exactly the real speed of the air at any point in front of or behind the propeller it is necessary to make use of some apparatus whose readings are not affected by the inertia of its moving parts.

M. Drzewiecki has succeeded in making measurements of the real speed at any particular point behind a propeller by use of a strobometer.

This strobometer was connected between the pitot tube, used to measure the velocity, and the manometer. Its function consisted in connecting the two only when the propeller was in a definite position relative to the pitot tube. The manometer being thus connected to the pitot tube once in a revolution and always at the same point relative to the blade, measured the true velocity at that point.

The strobometer was driven by a flexible coupling from the shaft and by adjusting this coupling it was possible to take the pitot tube reading at various positions relative to the blade.

The actual apparatus will be found fully described in M. Drzewiecki's work, "Théorie Générale de L'hélice," 1920.

The results of his experiments are interesting and throw light on this question of inflow. One such result is shown in Fig. 2 reproduced from this work.

In this test the pitot tube was placed 30 m.m.s behind the model at a radius of 300 m.m.s from the axis of rotation. The model propeller was 400 m.m.s radius and consisted of a single blade, the centrifugal pull of which was balanced by a counterweight. The angle of incidence on the blade was 3° when the model turned at 1,500 r.p.m. in a channel air speed of 16 metres per sec. The speed of the air was measured at twenty points on the circle relative to the blade. Fig. 2 was thus obtained.

It will be seen as the blade passes, the speed of air increases rapidly from the channel speed of 16 metres per sec. to just over 21 metres per sec. and then steadily diminishes to the channel speed slightly before the blade completes the revolution.

It is clear, therefore, from this experiment that, in this case at least, the blade is not affected by its inflow. Fig. 2 shows that the blade is always attacking air, the axial velocity of which is the speed of translation only. In Fig. 3 two curves similar to those in Fig. 2 have been superimposed but displaced by 180°. This gives an approximation to the variation of speed at a given point behind

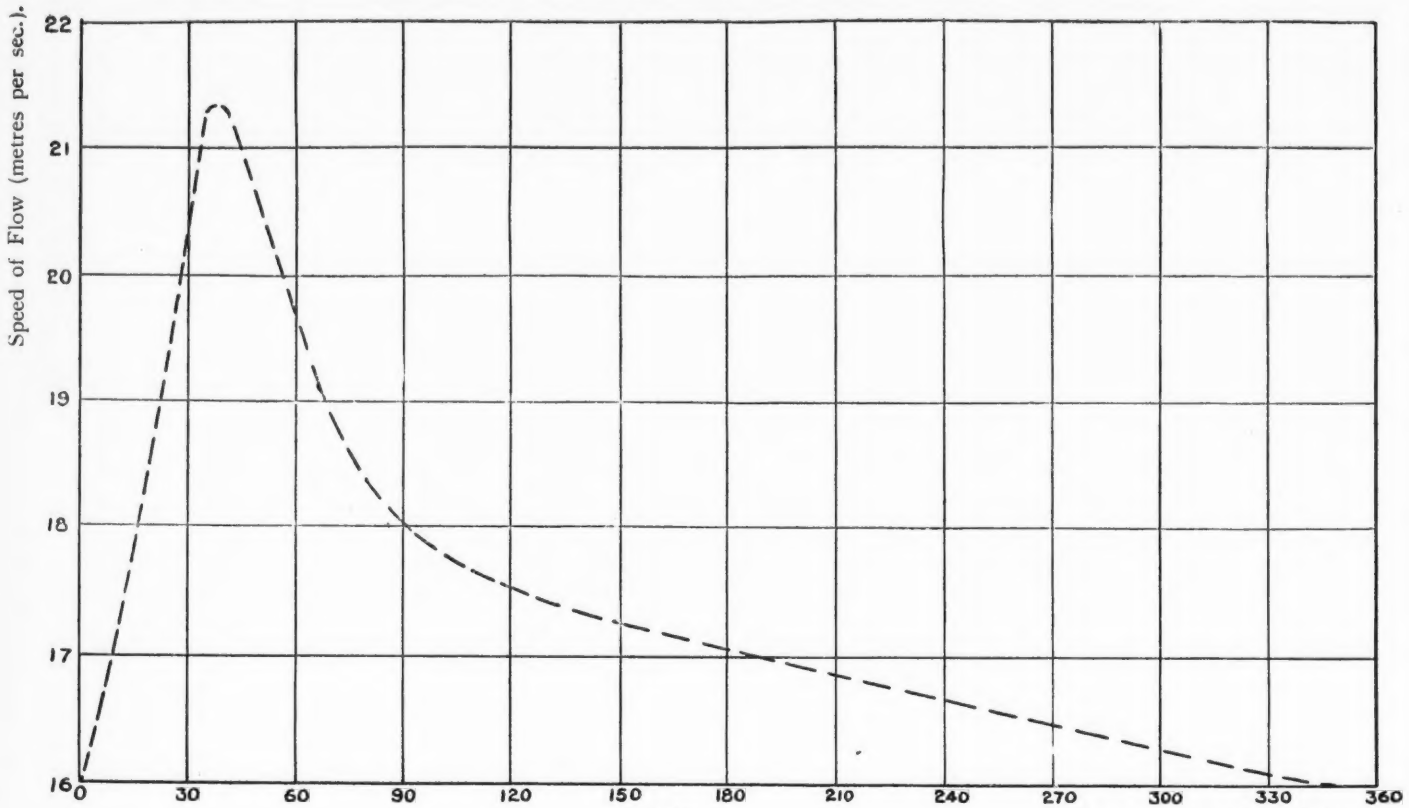

Speed of Flow (metres per sec.).
22
21
20
19
18
17
16
0
30
60
90
120
150
180
210
240
270
300
330
360
Angle from blade to Pitot tube.

FIG. 2.

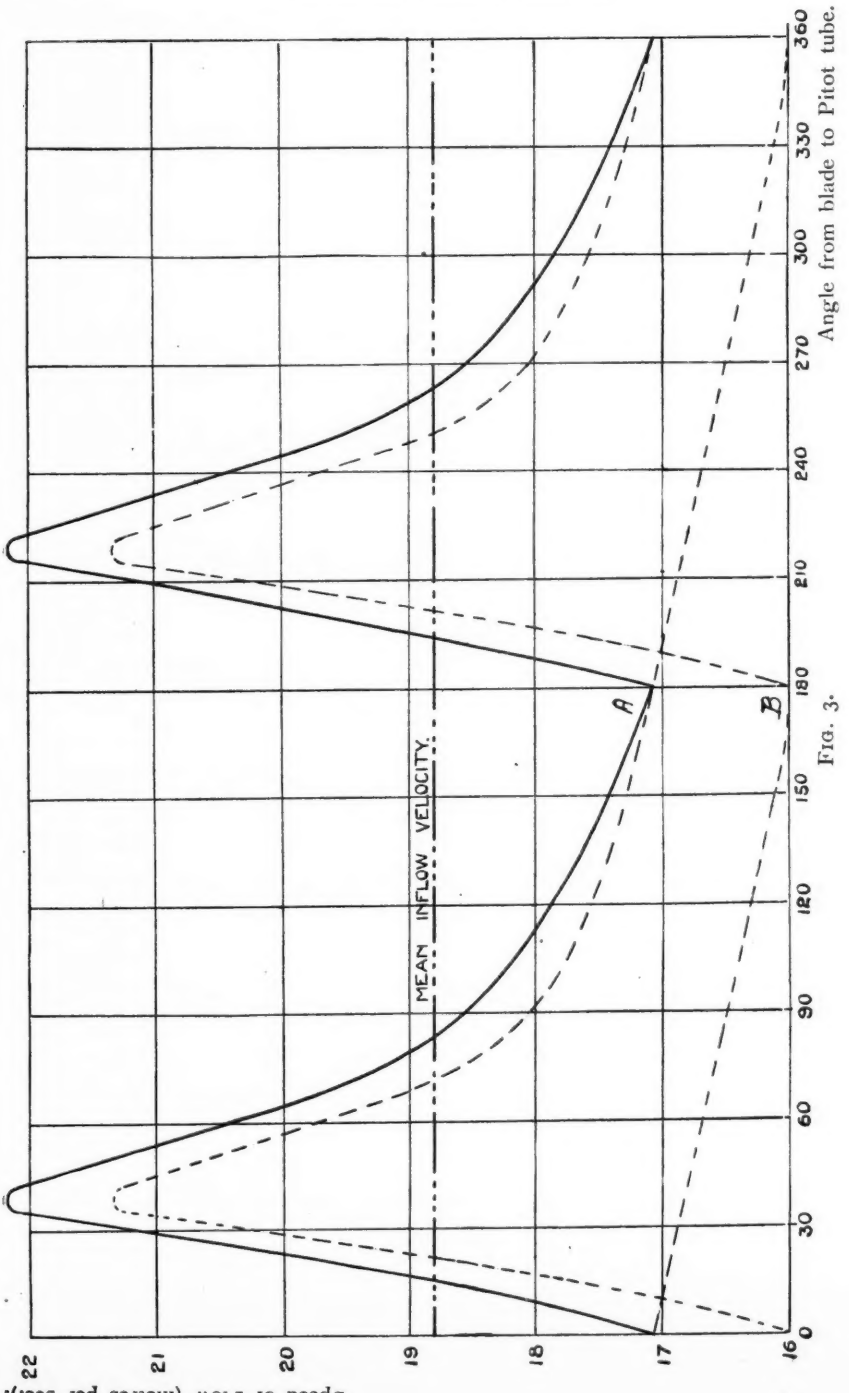

Speed of Flow (metres per sec.).
22
21
20
19
18
17
16
MEAN INFLOW VELOCITY.
A
B
0
30
60
90
120
150
180
210
240
270
300
330
360
Angle from blade to Pitot tube.

FIG. 3.

a two-bladed propeller. Figs. 4 and 5 show the same for a three and four-bladed propeller.

In the case of a two-bladed propeller it will be seen that each blade is attacking air having an axial speed equal to the speed of translation plus a small amount AB of the inflow on the previous blade. This amount, for convenience, is called the interference flow. In the case of the three blades each blade attacks air having a velocity equal to the speed of translation plus the interference flows CD and CE from the previous two blades.

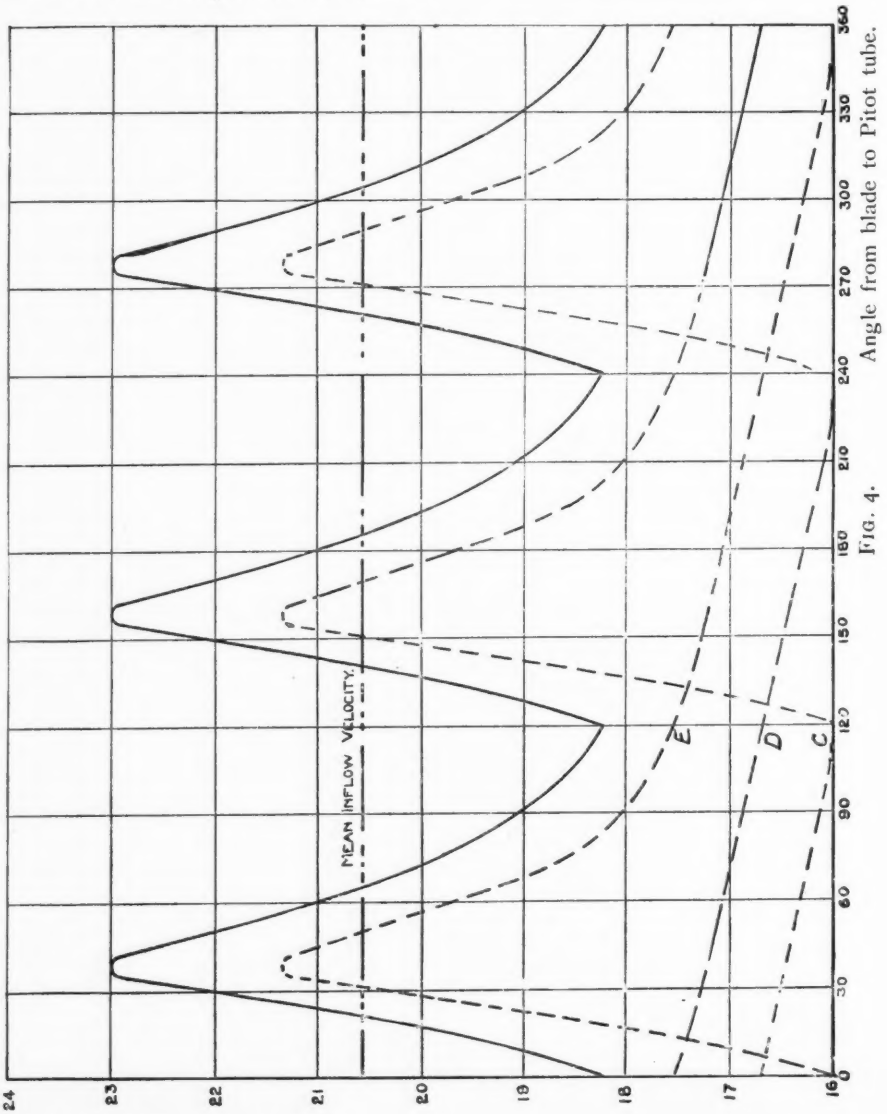


FIG. 4.

Similarly with the four blades, any one blade is influenced by the inflow set up by the previous blades, but not by the inflow caused by itself.

In each of the figures the dotted curves show the flow caused by each blade separately and the full curves give the resultant speed variation at the point of measurement. This latter curve is only approximate since the interference flow will have a secondary effect on the inflow and outflow. The chain line gives the average speed, and since the point of measurement was only 0.037 D between the plane of rotation, this speed may be considered approximately as the inflow speed.

It is not possible, of course, from this particular experiment to state as a general law the portion of the inflow which should be added to the speed of transla-

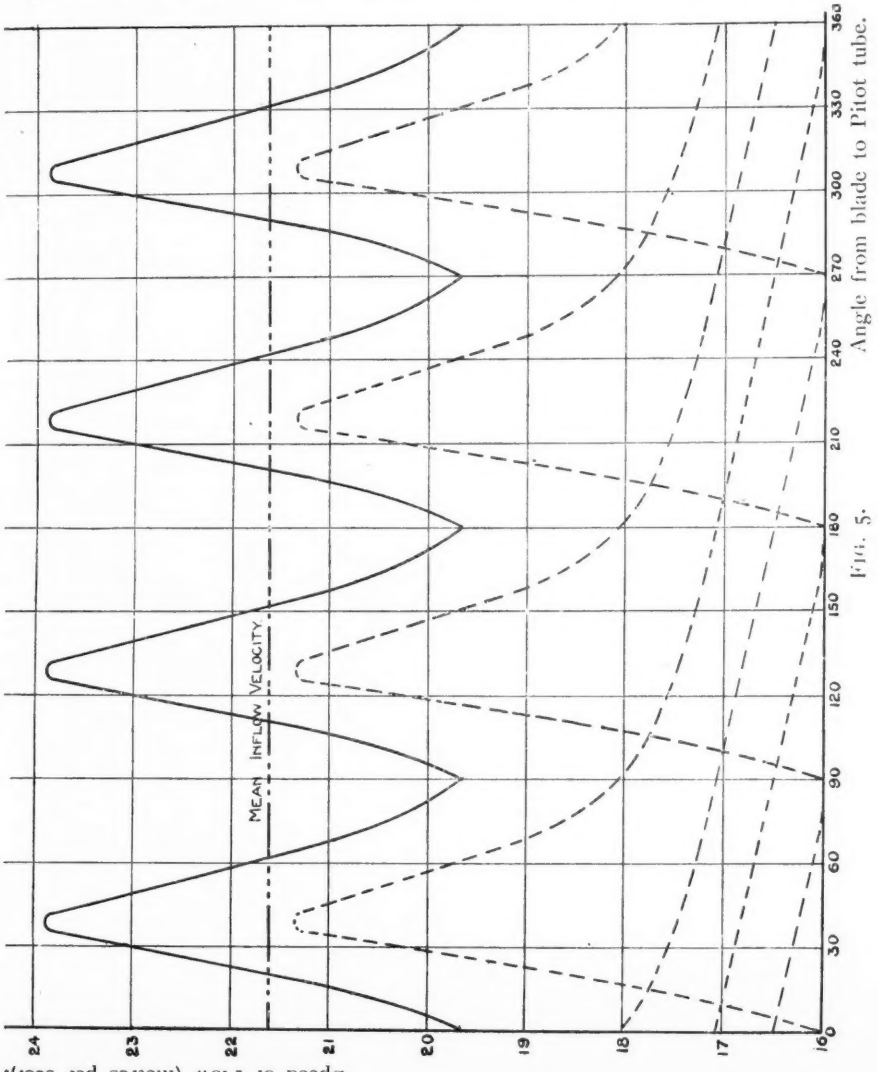


FIG. 5.

tion in order to give the true axial speed of air which the blade is attacking. The experiment suggests, however, the fraction cannot be taken as a constant but may vary with other factors such as the number and width of blades.

In the following table the interference flow is shown in column 2 as a fraction of the average inflow velocity, and if we assume that the mean inflow velocity is half the mean outflow velocity then column 3 shows the interference flow as a fraction of the outflow.

1. No. of Blades.	2. Interference Flow. Mean Inflow.	3. Interference Flow. Mean Outflow.
1	0	0
2	0.388	0.194
3	0.532	0.266
4	0.65	0.32
8	0.98	0.49

In Fig. 6 the values in column 2 are plotted against the number of geometrically similar blades.

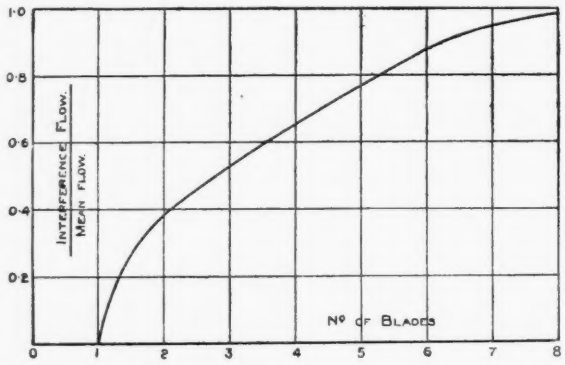


FIG. 6.

These values need checking by further experiment before their quantitative values can be entirely accepted. They are, however, significant, and throw light on what has for some time been a subject of controversy.

They indicate that—

(1) The conception that a propeller blade is influenced by its own inflow is erroneous.

(2) The propeller as a whole is, however, affected by the inflow, but that is due to blade interference.

(3) With a small ratio of total blade width to diameter the simple Drzewiecki is approximately correct, whilst with a large ratio the inflow theory with the inflow factor of 0.5 is correct. For propellers normally in use a compromise depending on the ratio is justified.

These recent experiments of Drzewiecki also give weight to the idea (often suggested but only recently experimentally tested by R. M. Wood at the Royal Aircraft Factory) that corresponding blade elements of successive blades in a propeller were equivalent to an infinite multiplane with a backward stagger and that blade interference might be corrected for by testing an aerofoil as one of such a multiplane series.

(Correspondence on the above Paper is invited.—EDITOR.)